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The Canadian Entomologist

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Similarities in the Histology of the Gut of Some Species of *Tribolium* Macleay (Coleoptera, Tenebrionidae) and *Oryzaephilus* Ganglbauer (Col., Cucujidae)

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Introduction

The alimentary canal of stored grain beetles is relatively simple compared to those of the higher orders of insects. But there are certain specializations from the generalized alimentary canal of the insect described by Snodgrass (1935). Striking similarities of structure have been observed in course of morphological investigation of the alimentary canals of two distantly related groups of beetles living on stored cereals. The differences between the two groups are few.

The purpose of this paper is to point out the similar anatomical and histological characters of the gut of *Tribolium* Macleay and *Oryzaephilus* Ganglbauer and to give a possible explanation for such similarities. Each genus is represented by two closely related species, *Tribolium* by *T. confusum* Duval and *T. castaneum* Herbst and *Oryzaephilus* by *O. surinamensis* (L.) and *O. mercator* (Fauval).

Materials and Methods

Insects used for dissection and fixation were taken from cultures kept at 30°C and 70% relative humidity in the laboratory. They were fed with wheat flour and oatmeal. Mature adults were used for the study of anatomy and histology. Dissections of the entire alimentary canal of insects were made separately with fine pointed needles under a binocular microscope (40X). Live insects taken directly from the temperature and humidity controlled chambers were chloroformed; elytra were removed and then the body was cut open from the dorsal side. All dissections were made on slides with insects submerged in drops of 0.5% saline solution. Methylene blue was used to distinguish different parts of the alimentary canal and Malpighian tubes from the large mass of fat bodies.

For histological study, about fifty adults of four species, *Tribolium confusum*, *T. castaneum*, *Oryzaephilus surinamensis*, and *O. mercator* were prepared in the following way. Insects were fixed directly from cultures in Mukerji's fixative (Mukerji, 1937; adapted by Sinha, (1953) for four to five days. After dehydration in absolute alcohol, the fixed insects were embedded in celloidin and paraffin successively. Serial sections of the entire body, four to six microns in thickness, were made in transverse and longitudinal planes. The technique used for sectioning sclerotized beetles has been described elsewhere in detail (Sinha, 1953). Carnoy's fixative (Lee, 1937) was also used as an alternative fixative. Specimens fixed in Carnoy's fixative were immersed in a mixture of 4 parts of concentrated nitric acid to 100 parts of 90% alcohol, for softening the sclerotized cuticle. Serial sections on a slide were cleared in cedarwood oil and mounted in permount after a dip in xylene. Except for a number of sections of *Tribolium castaneum* none of the sections were stained. The former were stained in Mallory's triple stain and Delafield's hematoxylin and eosin in connection with the study of the alimentary system (Sinha, 1958 in press). Unstained sections

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were found to be as good as, or better in some respects, than stained sections for study of cellular details with the phase contrast microscope. A phase contrast microscope was used for the entire study. The elimination of lengthy and complicated staining processes, which is made possible by the use of phase microscopy has enabled the author to examine a large number of slides comprising individuals of four different species of insects in a reasonably short time. Unless one is interested in the physiological and biochemical aspects of specific cells, this method seems to be extremely convenient for general histological work.

Drawings of the whole mounts were made from images on a screen projected by a microprojector. Sections were drawn by camera lucida. Photomicrographs were taken through the phase contrast microscope at a 40X magnification.

Systematic Position of the Species

Unfortunately, there is no comprehensive work dealing with the phylogenetic relationships within the families of Coleoptera. The four species studied in this work represent two families of Coleoptera. Standard editions on classification of insects (Brues et al., 1954) have classified them in the following way:

Tribolium confusum and *T. castaneum* (sub-order–Polyphaga, superfamily–Tenebrionoidea, family–Tenebrionidae)

Oryzaephilus surinamensis, *O. mercator* (sub-order–Polyphaga, superfamily–Cucujoidea, family–Cucujidae).

The two species of each genus chosen for comparison show very little difference in the structure of their digestive tracts. Since each group of species has diverged from the common suborder Polyphaga at the superfamily level, it might be expected that significant differences would occur in both external and internal anatomical structures.

Characters of Alimentary Canal

No attempt has been made here to describe every structural detail of the alimentary canal of the four species studied. Although the anatomy of the alimentary canal of any of the species, except *Tribolium castaneum* (Sinha, 1957, in press), has never been described, only common characters shared by a member or members of each genus have been chosen for this study. Detailed anatomical description of the three undescribed species will be published elsewhere. A list of such selected characters is given below. Unless otherwise stated, the following characters of the alimentary canal are shared by all the four species of the two genera *Tribolium*, and *Oryzaephilus*.

The list excludes any character which may fall in any of the following categories: (1) Characters showing individual variation, (2) Artifacts which are frequently confused as true characters, and (3) Characters which are known to be uniform throughout the order Coleoptera.

A few of the characters in the list, such as, six Malpighian tubes, may later, with the increase of our knowledge of the internal structure of other species, be proved to be those of higher categories than species or genera, and may not indicate true parallelisms. But, at the present state of our knowledge, it is generally agreed that the number of Malpighian tubes is highly variable in different groups of insects, and even within a single order. In Coleoptera, most pentamerous forms have 4 tubes, and other groups have 6; but there are exceptions, as *Hydrophilus* with 6, and *Sitaris* 4 (Snodgrass, 1935). Such generalizations can be questioned in view of more recent work in this field. For instance, the family Cucujidae have five jointed tarsi as a general rule rarely with 4 jointed hind tarsi (Comstock, 1940). But both species of the family studied here have six Malpighian tubes. Of course, it is not possible to select characters of true

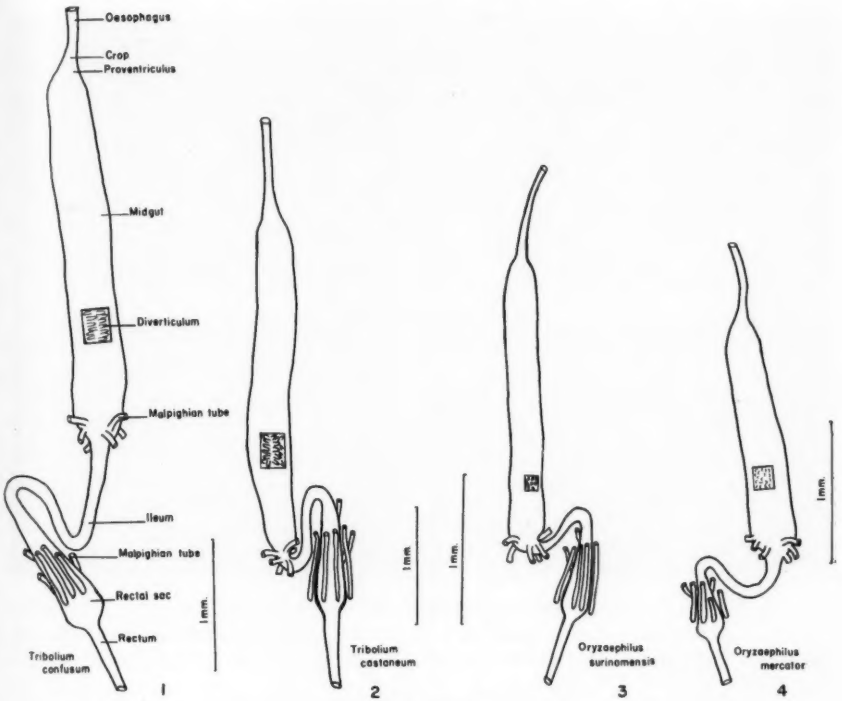

PLATE I

Figs. 1-4. Alimentary canal, gross anatomy; pharynx and the Malpighian tubes (except the proximal and distal ends) are not shown; diverticula are distributed throughout the midgut.

taxonomic significance until at least the representative members of each taxon has been worked out, using reasonably uniform techniques. The following are the characters of the alimentary canal showing similarities in two groups of species, *Oryzaephilus surinamensis, O. mercator, Tribolium confusium,* and *T. castaneum.*

Characters of gross anatomy

Alimentary tract, one simple tube.
Alimentary tract slightly longer than body.
Proventricular constriction indistinguishable.
Midgut with very small or large diverticula.
Midgut, a long almost uniformly wide tube.
Malpighian tubes, six in number.
Malpighian tubes with distal portions adhering against the outer wall of rectum.
Ileum with S shaped convolution.
Rectal sac, cone-shaped.
Mouth cavity, spindle-shaped.
Labial glands present.

Characters of foregut

Mouth cavity with patches of hairs on the wall.
Pharynx with teeth on a part of dorsal surface.

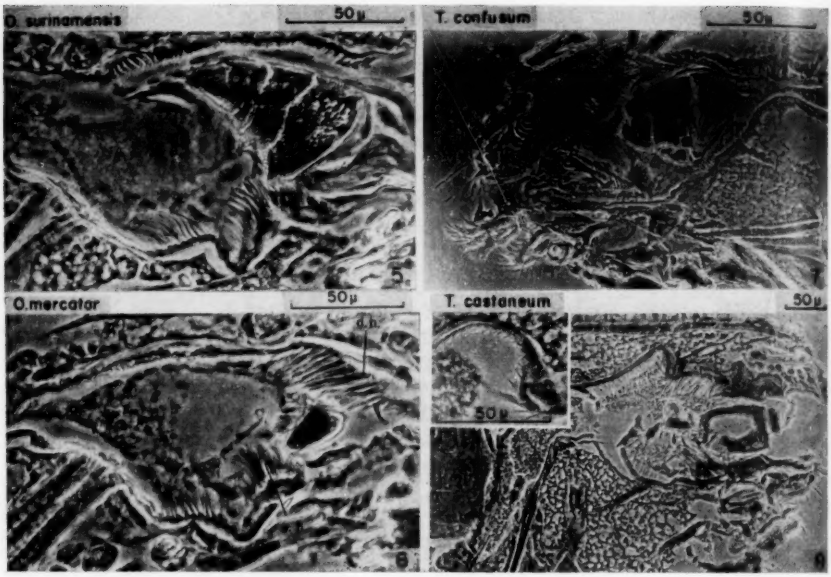

PLATE II

Figs. 5-8. Longitudinal sections through the head showing the mouth cavity and pharynx. Note the characteristic arrangement of dorsal and ventral tufts of hairs. d.h.–dorsal hairs; v.h.–ventral hairs; t–teeth.

Fig. 9. Longitudinal section through the dorsal wall of the pharnyx showing the teeth. t–teeth like hairs.

Oesophagus and crop, intima thrown into irregular folds.
Oesophagus, intima thin.
Circular muscles of oesophagus and crop, 1 strand thick.
Circular muscles of proventriculus, number of strands, 1-2.
Longitudinal muscles in oesophagus and crop, 1-2 strands in thickness.
Longitudinal muscles in proventriculus, 1-2 strands thick.
Peritoneal layer of foregut absent or indistinguishable in most parts.
Proventricular pads, regular, 8 in number.
Proventricular valve present (except *O. surinamensis*).
Junction of fore- and midgut with sphincter.
Epithelium with cuboidal cells.

Characters of midgut

Epithelial cells columner, elongate.
Epithelial cells with nuclei usually in the middle.
Epithelial cells with detectable striated borders at the free ends (questionable in *Oryzaephilus mercator* and *Tribolium confusum*).
Epithelial cells with vacuoles.
Epithelium, type of secretion, merocrine.
Epithelium, type of cells, polyphasic.
Epithelium, type of cell activity, asynchronus.
Nidi with simple arched columner cells.
Nidi, arrangement separate.

Basement membrane outside nidi.
Peritrophic membrane absent.
Circular muscles, number of strands, 1-2.
Longitudinal muscles, distribution sparse.
Longitudinal muscles, 1 strand thick.

Characters of hindgut

Pyloric valve present.
Cells of pyloric valve arranged in a semicircle.
Ileum, epithelium thrown into folds, number variable.
Ileum intima with hairs.
Malpighian tube with 2 to 3 large cells in cross section.
Malpighian tube, striated border at free ends of cells.
Rectal sac with thick intima.
Rectal sac with 6 pads.
Longitudinal muscles of rectal sac, vacuolate, large and rounded in longitudinal section.
Longitudinal muscles of rectal sac, 1 strand thick, arranged in a zigzag pattern.
Rectum, intima thrown into irregular folds.
Circular muscles of rectum, 1 strand thick.

Analysis of Characters

An analysis of the characters outlined above indicate that the structures showing the parallel changes in the alimentary canal are distributed uniformly throughout the entire system.

In gross anatomy, the most striking feature is the general appearance of the whole alimentary canal of all four species. Except for a few differences, such as the size of the diverticula (Sinha, 1958) (extremely small in *Oryzaephilus* spp. and conspicuously large in *Tribolium* spp.), it is difficult to distinguish the alimentary canals of the species of one genus from those of the other genus.

In all species, the midgut comprises more than half of the length of the entire canal. The distributions of the diverticula (knob-like swellings in *Oryzaephilus* spp.) are uniform throughout the length of the midgut in all four species. The character, S-shaped convolution of the ileum has been used rather loosely. In natural position, as revealed by serial sections of whole insects, all four species of the two genera show a similar position of parts with respect to other organs. Covered intimately with fat bodies, the strongly muscular rectal sac is usually the first organ to be encountered immediately below the dorsum when an insect is dissected open. In all cases, the hindgut shows peristaltic movement in freshly chloroformed specimens.

Six Malpighian tubes which extend forwards in the haemocoele from their origin at the junction of midgut and hindgut are dark with nitrogenous waste products enclosed inside. They form loops and extend backwards terminating against the wall of the rectal sac.

The presence of reduced and lobulate glands in the heads of *Oryzaephilus surinamensis, O. mercator, Tribolium confusum* and probably *T. castaneum* is of considerable significance. Except in the family Coccinellidae (Pradhan, 1936, 1939) labial glands are unknown in the order Coleoptera (Snodgrass, 1935; Day and Waterhouse in Roeder, 1953). These glands will be described in detail in a separate paper.

The wall of the mouth cavity contains irregularly arranged tufts of hairs which are directed posteriorly in all four species with minor variation of pattern.

Only a small area of the dorsal surface of the cavity contains a patch of minute teeth. Proventricular invaginations are of the same type in the arrangement of muscular strands and epithelium. Although the species of *Oryzaephilus* lack stout hairs on the proventriculus, they resemble the species of *Tribolium* in having eight well marked proventricular folds. The sphincter-like arrangement of a large number of circular muscles at the junction of foregut and midgut is

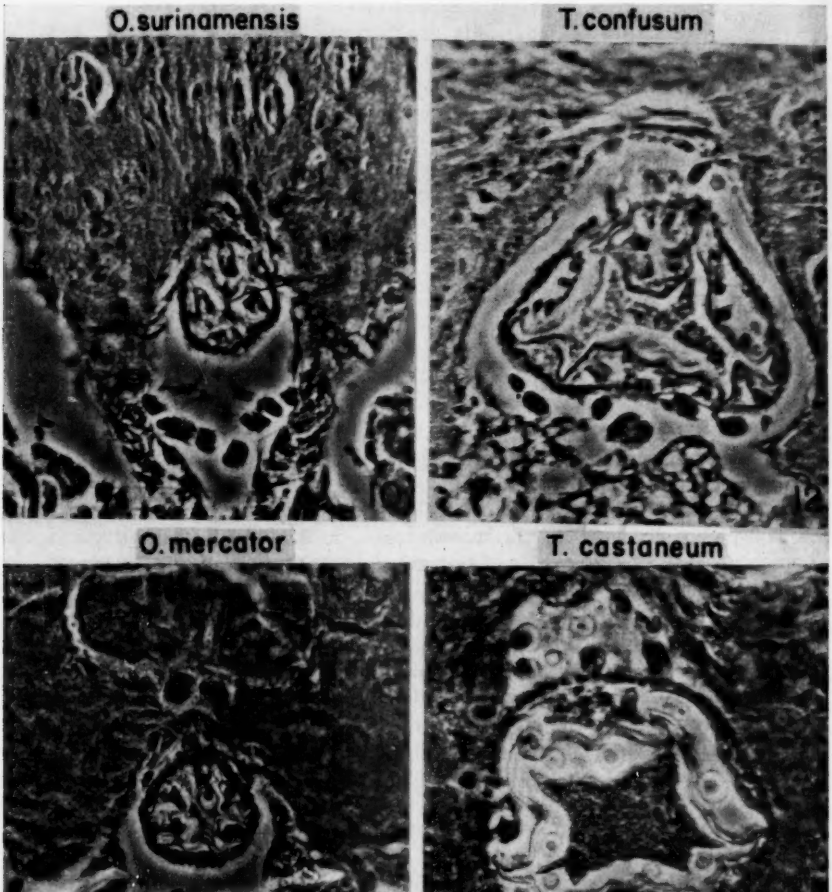

PLATE III

Figs. 10-13. Transverse sections through the head showing the brain and the oesophagus. i—irregular folds of intima.

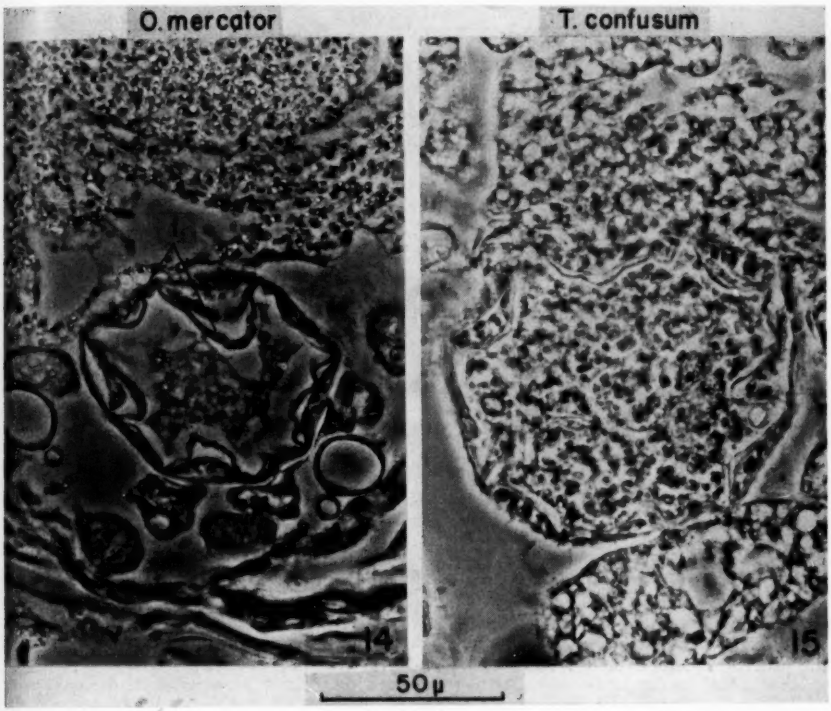

PLATE IV

Figs. 14-15. Transverse sections through the proventriculus. f.—folds of intima and epithelial cells.

found in all four species. This appears to be a convenient device to regulate the movement of food into the midgut.

The uniformity of cellular pattern is conspicuous in the midgut. The shape, size, and the type of secretion of cells of the epithelium are strikingly similar in all four species. The regenerative cells of the nidi extend into large diverticula in *Tribolium confusum* and *T. castaneum*. But the regenerative cells of nidi of *Oryzaephilus surinamensis* and *O. mercator* are localized in one layer within the small protuberances of the midgut. In spite of this difference, nidi of the species of both genera are of the same simple pattern described and illustrated by Snodgrass (1935), that is, the pockets are usually closed by an overgrowth of surrounding digestive cells, and the general contour of the inner surface of the epithelium hardly gives any indication of the position of the nidi. Whether the regenerative cells are localized in evaginated diverticula or slight protuberances of the midgut, the basement membrane is, in all four species, outside the nidi.

The mode of secretion of the cells of the epithelium of the midgut is merocrine, that is, epithelial cells produce droplets containing enzymes and other secretory substances. Epithelial cells in the midgut of any of the four species observed (under phase contrast microscope) appear to distend considerably at the free end while vacuoles seem to be conspicuous in different parts of the cell. A granular globule or droplet is seen to have detached from the distal boundary

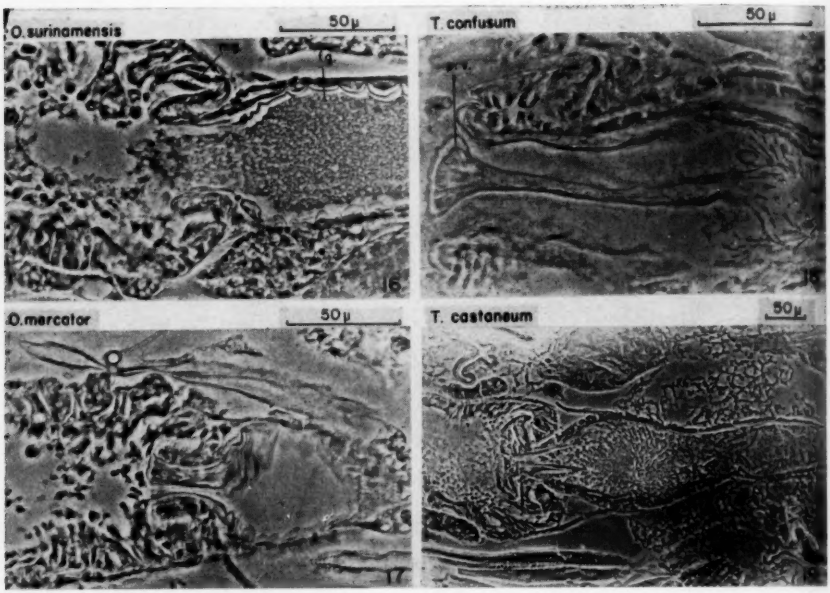

PLATE V

Figs. 16-19. Longitudinal sections through the junction of foregut and midgut showing the proventricular valve. fg.–foregut; mg.–midgut; p.v.–proventricular valve.

of the cell in some portions of the epithelium. Hirsch (1931) has pointed out that the secretion of the midgut of most insects (especially herbivorous insects) is a continuous arhythmic process (that is, the time of restitution is equal to the time of extrusion). Using his terminology, all species used in this study have the polyphasic type of epithelial cells of midgut. Cells are able to repeat twice or more often the flow of irreversible processes following the first extrusion; in other words, cells repeat the secretory process (restitution) before cellular degeneration. The secretory activity of cells in the midgut is not synchronous in any of the four species studied. The epithelial cells in these species are never found to be in the same phase of secretion. Droplets at the apical ends of epithelial cells were never found all along the lumen of the midgut in one insect sectioned. Such observations during the preliminary stage of study give one the erroneous impression that the secretions are localized to particular portions of the midgut. Pradhan (1939) has described similar asynchronous activity of polyphasic cells of midgut as characteristic of herbivorous Coccinellids as opposed to synchronous and monophasic epithelium of carnivorous Coccinellids.

The presence of a pyloric valve or a muscular invagination at the junction of midgut and hindgut is a common feature in all four species. The intima of the ileum contains rows of comb-like hairs in the species of *Tribolium*. Although they are smaller and different in arrangement, minute hairs are also present in the intima of the ileum of *Oryzaephilus* spp. The inner wall of the ileum is thrown into a number of folds in all species.

Malpighian tubes are very similar in the two groups of species. They have a ring of two to three large cells (seen in cross section) and numerous granules

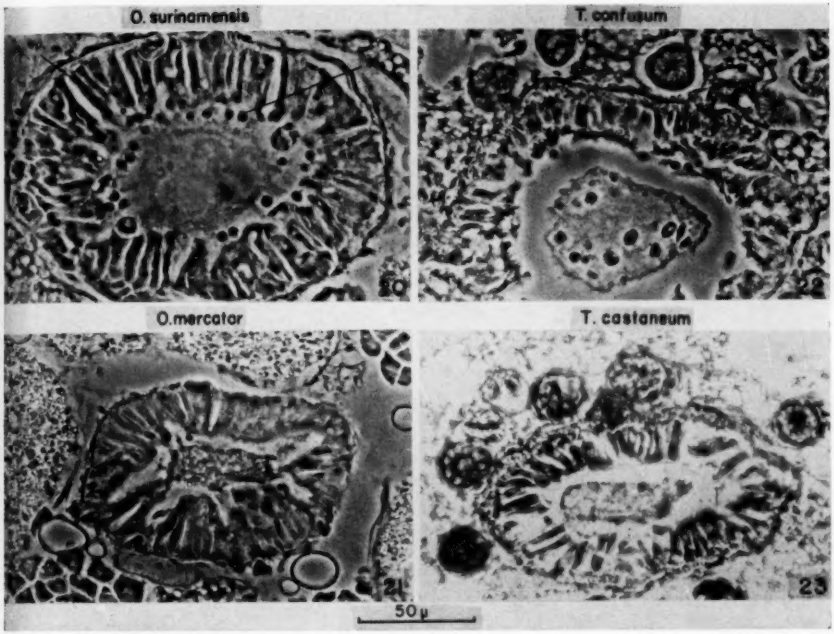

PLATE VI

Figs. 20-23. Tranverse sections through the midgut. ep.—columnar epithelial cells; s.—secretion globule.

of uric acid crystals. The distal portions of the Malpighian tubes adhere against the wall of the rectal sac loosely. No peritoneal sheath encircling the Malpighian tubes around the rectal sac was detected in any species. The sinuate longitudinal muscles of the rectal sac are unusually large and are very similar in the two groups of species. Miller (1931) has recorded four to seven rectal pads in the rectal sac of *Meracantha contracta*. The number of rectal pads is six in the species studied here.

Discussion

The structure of the alimentary canal is usually modified by the feeding habit and the type of food consumed by an animal (Prosser, 1950). The complex alimentary canal of higher animals is merely an efficient device for retaining food substances close to the digestive and absorptive surfaces and especially equipped with the mechanisms for ingestion and egestion (Snodgrass, 1935). Insects feed on a wide variety of food materials. Correspondingly, modifications of insect gut are numerous. Functional aspects of the alimentary canal are often intimately correlated with structural modifications; for example, several species of Homoptera, feeding exclusively on a liquid diet possess an unusual modification, the filter chamber, a device by which the excess of fluid is directly transferred from the anterior portion of the midgut to the hindgut.

Yonge (1936) has dealt with the evolution and adaptation of the digestive system in the animal kingdom with special reference to Metazoa. According to him, there are five functional subdivisions of the alimentary canal as against three morphological subdivisions, foregut, midgut and hindgut. These functional

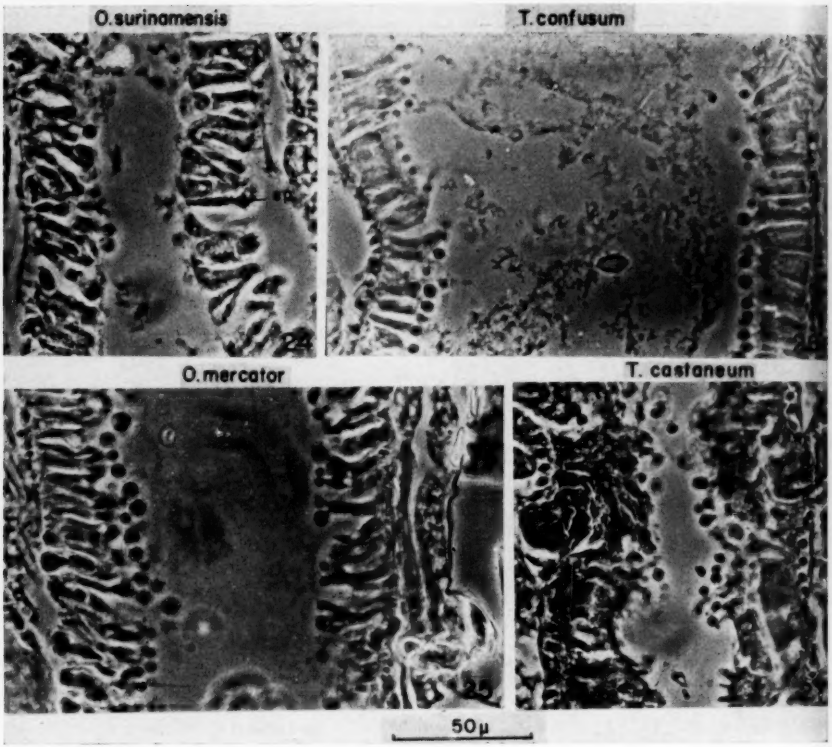

PLATE VII

Figs. 24-27. Longitudinal sections through the midgut. ep.—columnar epithelial cells; s.—secretion globule.

subdivisions (morphological counterparts are given in parenthesis) are: (1) the reception of food (mouth and mouthparts, buccal cavity); (2) conduction and storage of food (Oesophagus, crop, and probably proventriculus); (3) digestion and internal triturition (midgut); (4) absorption (midgut, and hindgut for water); and (5) conduction and formation of faeces (rectum).

Since the nature of the foodstuffs is the major factor in affecting modifications or in the selection of already existing modifications in these regions of special functions, we must consider the food of all the species studied. These insects feed on a wide variety of dried products, including every kind of grain, flour, starchy material, in fact, almost all plant products used for human consumption (Metcalf et al., 1951). Howe (1956) has stated that *Oryzaephilus surinamensis* is found chiefly on cereal products and *O. mercator* chiefly on oil-seed products. Whatever may be the preference, food of most of these insects is always dry and starchy; for example, there is 13.3% moisture and 74.1% carbohydrate available in a sample of refined wheat flour (Mukerji and Sinha, 1953).

A peritrophic membrane is known to occur in Coleoptera (Snodgrass, 1935). Only *Meracantha contracta* Beauv. (Miller, 1931), out of five species of the family Tenebrionidae studied so far by different authors (Auten, 1933; Krall and

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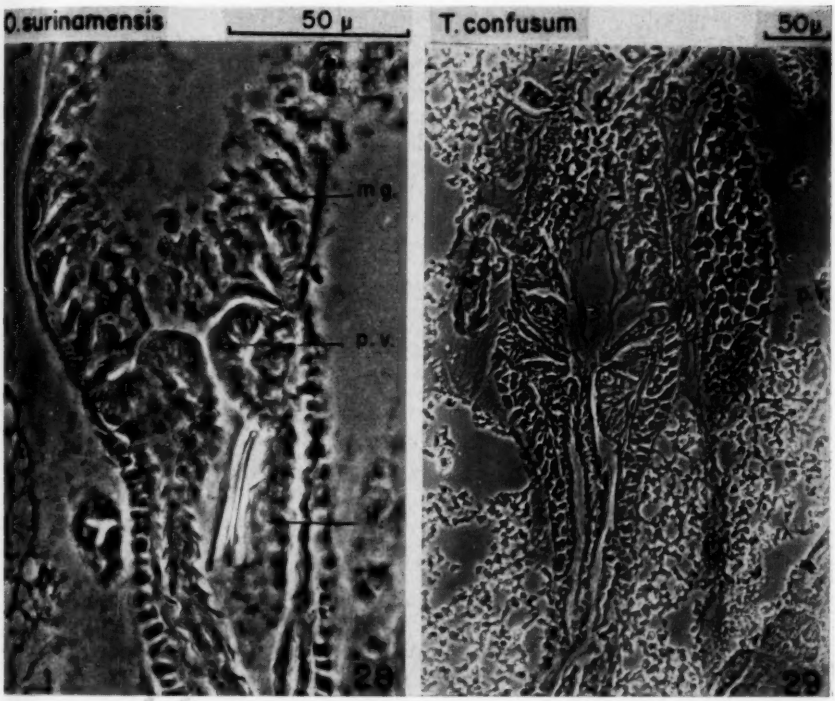

PLATE VIII

Figs. 28-29. Longitudinal sections through the junction of midgut and hindgut showing the semicircular pyloric valve. il.–ileum; mg.–midgut; p.v.–pyloric valve.

Jones, 1943; Sinha, 1957, in press) have a peritrophic membrane. *M. contracta* is a phytophagus beetle living beneath the bark of oak and maple trees. Members of *Oryzaephilus* and *Tribolium* do not possess a peritrophic membrane. Whether the solid food consumed has any bearing on the formation or absence of a peritrophic membrane is questionable.

The conservation and regulation of available water is one of vital problems faced by most insects. In order to meet this challenge almost every part of the insect body has been greatly modified. Those insects, feeding exclusively on dry food not only eat more food at low humidities and utilize a part of the food as water, (Fraenkel and Blewett, 1944) but also conserve water by developing special mechanisms. Thus *Tribolium* and *Silvanus* (a genus of Cucujidae close to *Oryzaephilus*) can grow well with only 6% water content (Wigglesworth, 1953). The alimentary canal of *Tribolium* and *Oryzaephilus* has played its part for conservation of scarce water supply mainly in three ways: firstly, in the possession of the cryptonephridic arrangement of Malpighian tubes (Potts, 1935; Patton in Roeder, 1953) which appear to reabsorb water from the wall of the rectal sac; secondly, the muscles of the rectal sac are unusually large and arranged in a zig zag pattern. Such an arrangement of muscle probably enables the rectal sac to distend enormously for the storage of a large quantity of excreta for a long time until the maximum possible extraction of water is made from them. A large

quantity of starchy material has been recovered from the rectal sacs of about 40 insects starved for more than a week; thirdly, the presence of six strong rectal pads which help in the final extraction of water from the excrement (Wigglesworth, 1932). It has been found in some insects feeding on dry food that the contents of the hindgut are semifluid at the anterior end, but in the rectum they become dry and the excreta are ejected as a dry powder (Waterhouse and Day in Roeder, 1953). Besides I have observed the characteristic hexagonal shape of a large number of pellets of excreta in these insects.

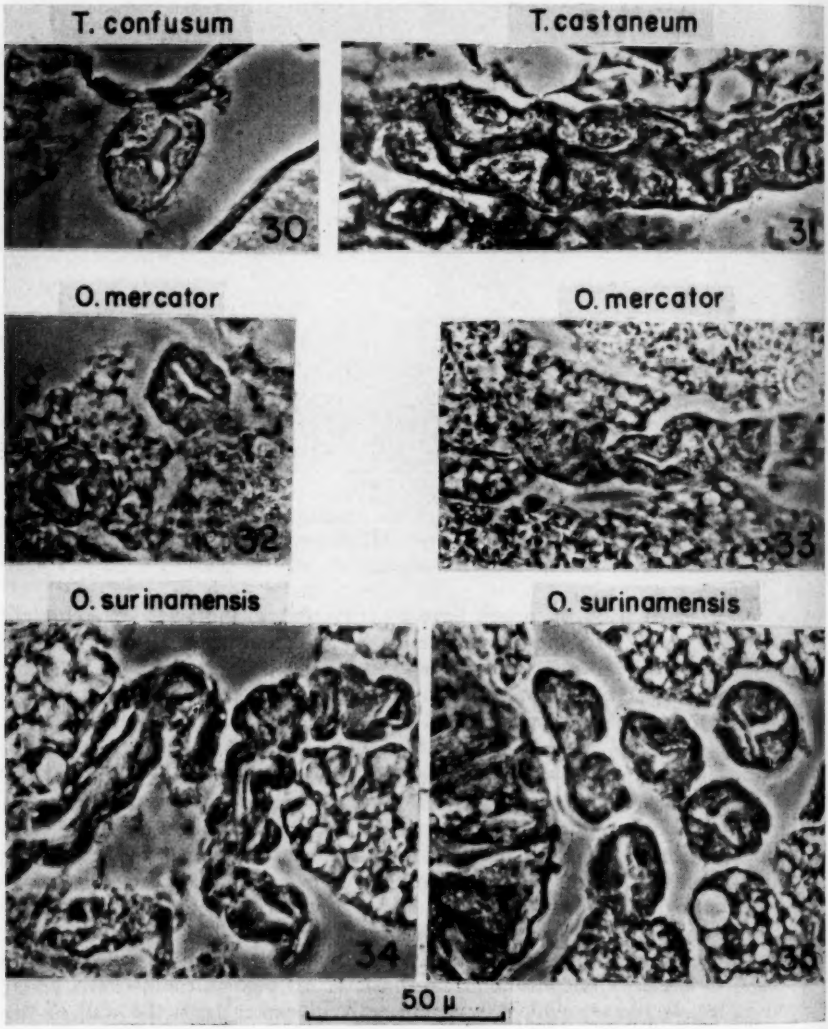

PLATE IX

Figs. 30, 32 and 35. Transverse sections through the Malpighian tubes showing the triradiate canals.

Figs. 31, 33 and 34. Longitudinal sections through the Malpighian tubes.

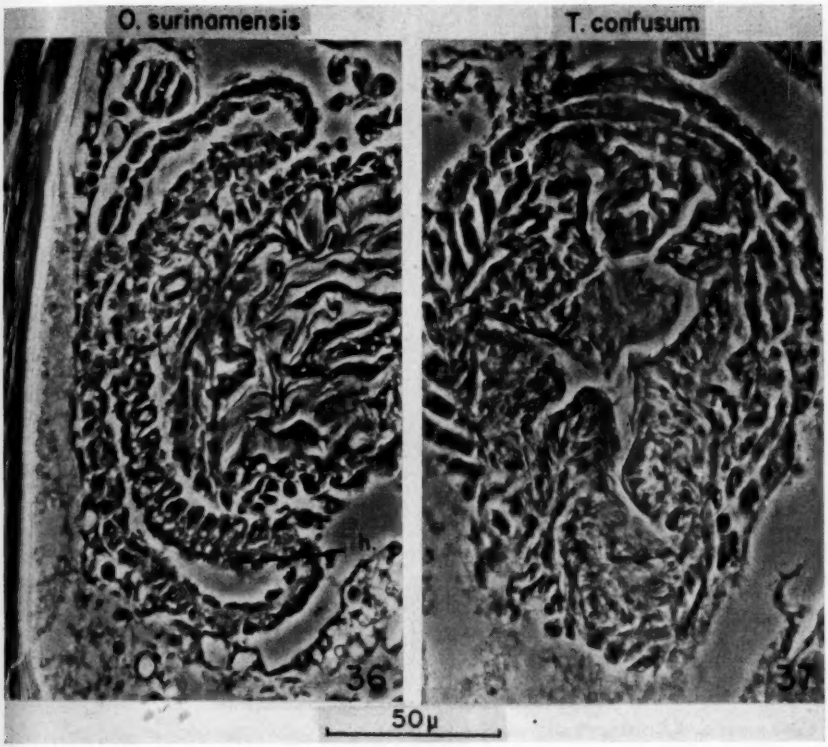

PLATE X

Fig. 36. Longitudinal section through the ileum. h.–hairs.
Fig. 37. Diagonal section through the ileum showing the hairs.

Pradhan (1939) has shown that the epithelium of the midgut of the herbivorous Coccinellid *Epilachna* is polyphasic and asynchronous in activity as opposed to a monophasic and synchronous type of epithelium in the carnivorous Coccinellid *Coccinella*. He explains that this difference is due to the fact that a herbivore can go on feeding continuously whereas a predator feeds intermittently largely depending upon the availability of the prey. He further points out that the large quantity of food, poor in concentration of nutriments must be held in the gut for a long time before the nourishment can be absorbed from it. A similar explanation may apply to the modification of epithelial cells and the length of midgut among four species of *Tribolium* and *Oryzaephilus*.

A number of species of *Tribolium* (Good, 1935; Hinton, 1948) and a few species of *Oryzaephilus* (Grouvelle, 1912) have been found in nature beneath the bark of trees and in other similar environments. Even some members of all four species studied are known to occur out-of-doors. Perhaps the alimentary canal of these beetles had been modifid to digest dry and starchy food most efficiently long before they invaded stored cereals provided by man. Mechanisms to utilize extremely dry food have helped only some species of each genus to enter and establish themselves successfully in a previously unexplored niche during the

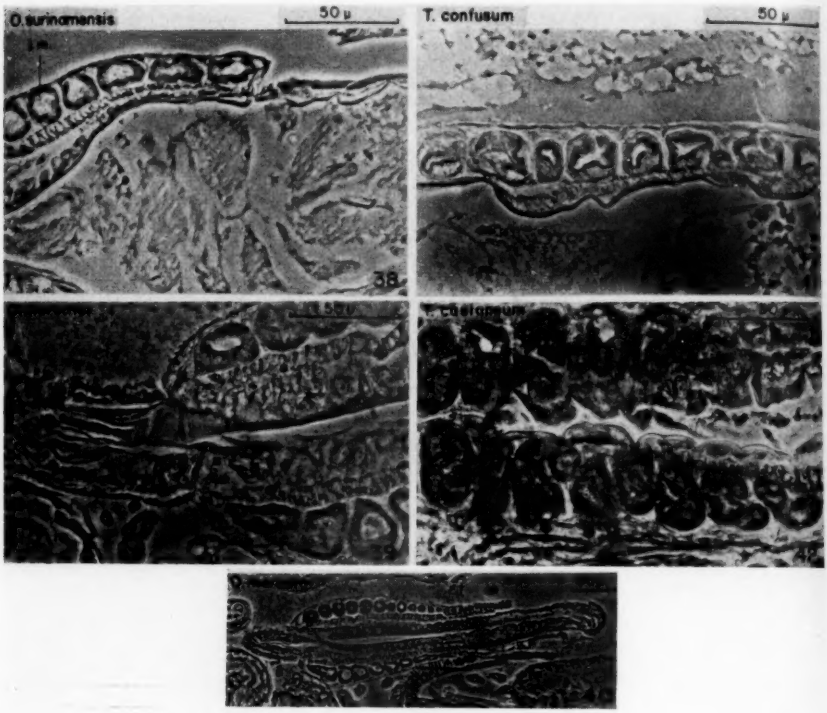

PLATE XI

Figs. 38-40. Longitudinal section through the rectum. l.m.—longitudinal muscles. Note the circular shape of the muscles because of the zig zag arrangement of the longitudinal muscles around the rectal sac.

recent historical past. Such a supposition can not be confirmed until the alimentary canals of some species living exclusively in nature are thoroughly studied. *Merocantha contracta* Beauv., a Tenebrionid beetle living under the bark of maple and oak trees shows some significant specializations in its alimentary canal, such as, the presence of a peritrophic membrane (Miller, 1931), not shared by any other Tenebrionid species in which the alimentary canal has been described. A peritrophic membrane is absent in the midgut of *Bolitotherus cornutus*, another Tenebrionid living on moist fungus (Auten, 1933).

Noble and Jaeckle (1928), after studying the morphology and histology of the tree-climbing apparatus of the Amphibia, came to the conclusion that strikingly similar characters have developed without any relation to the tree climbing habit. The digital disk apparatus (covered ventrally with a superficial layer of vertically elongated, fibrous and distally free cells between which there empty a series of convoluted mucous glands) was fully established before certain groups of frogs became arboreal. According to these workers, a thorough analysis of many so-called 'marvellous adaptations' in the Amphibia may reveal that these are probably the cases in which the modifications arose before the function. Similar explanation for the similar characters of the alimentary canal of stored

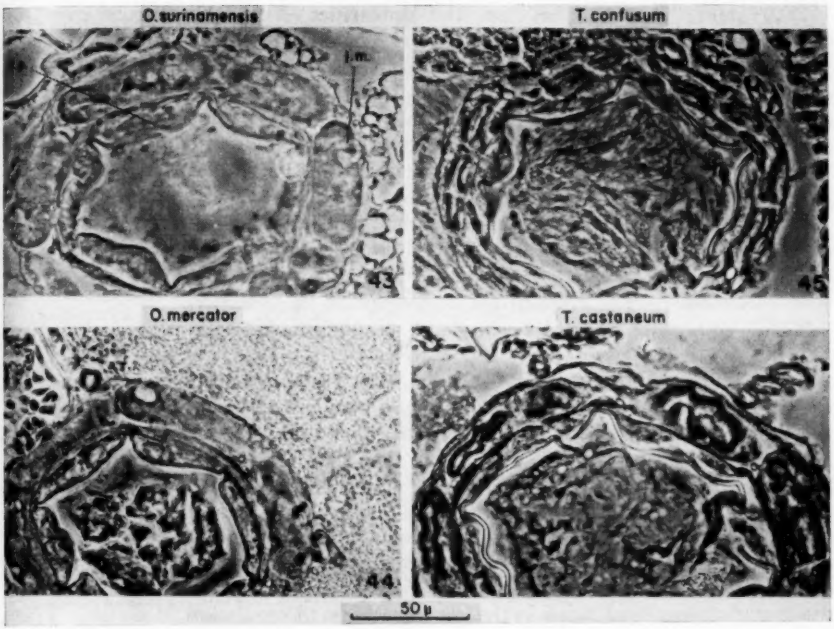

PLATE XII

Figs. 43-46. Transverse sections through the rectal sac. l.m.–longitudinal muscle; r.p.–rectal pad.

All photomicrographs were taken with Zeiss Phase attachment. All sections were unstained except those of *Tribolium castaneum* which were stained with Mallory's Triple stain.

cereal insects would require more data. Nevertheless, it is an interesting possibility.

Most of the common characters of the alimentary canal of *Tribolium* and *Oryzaephilus* can be explained by either of the two ways. (1) They may be results of parallel evolution. Simpson (1949) states that groups of animals which are already adaptively and structurally similar undergo similar changes in the same direction which enables them to exploit similar opportunities to develop a modified way of life. These groups are usually closely related to start with, and undergo similar mutations as a means of change in structure. Considerable amount of work has been done in describing parallel evolution in the external morphology of different groups of animals; for instance, the size and coiling in different lines within the Lamellibranch mollusc *Gryphaea,* (Carter, 1951), the tibial spurs in different genera of Saturniid moths (Michener, 1949), the horns or long knobs on the skull within the Ungulate group *Titanotheres* (Osborn, 1929). Also, as mentioned before, Noble and Jaeckle (1928) have shown that adhesive pads in tree frogs of two distantly related genera, *Hyla* (Fam. Hylidae) and *Polypedes* (Fam. Polypedatidae) have undergone similar changes in both external morphological and histological structures. (2) The alternative explanation is that they are simply homologous structures retained from the common ancestor.

The question as to which explanation is correct can not be settled until the alimentary system of the form ancestral to both groups is described.

Whatever may be the case, the similarities in the alimentary canal of *Tribolium confusum*, *T. castaneum*, *Oryzaephilus surinamensis*, and *O. mercator* appear to have definite correlation to their ability to feed on almost every kind of dry food available for human use. Morphological specialization is probably one of the factors which has qualified them for exploiting an endless variety of foodstuffs stored in warm and protected human habitats. They have spread and established themselves rapidly throughout the world (Black and Cotton, 1930; Cotton, 1950; Howe, 1956; Metcalf et al., 1953) in the historical past (Hinton, 1948). They now far exceed their near relatives living in nature, both in number and range of distribution. Perhaps such specializations arose as a result of random mutations long before they had any functional significance, and were subsequently selected for in the course of evolution.

Summary

Similarities in the anatomy and the histology of the alimentary canals of the stored cereal insects, *Tribolium confusum* Duval, *T. castaneum* Herbst, *Oryzaephilus surinamensis* (L.) and *O. mercator* (Fauvel) have been reported. These similarities involve a 'cryptonephridic' arrangement of Malpighian tubes, prominent rectal pads, strong and sinuate longitudinal muscles on the outer wall of the rectal sac in addition to a number of other characters distributed throughout the entire alimentary canal. The common specializations in the alimentary canal have been found to be correlated with the ability of the insects to feed on almost any kind of dry and starchy food available for human use. Some of the modifications have aided in the conservation and regulation of water. These specializations have been assumed to have arisen, as a result of random variations, long before they had any functional significance. Parallelism or the retention of homologous characters from the common ancestor have been suggested as possible explanations for the similarities of the gut of two distantly related genera of insects.

Acknowledgments

Grateful acknowledgment is made to the National Research Council of Canada for the funds made available for this work. I am thankful to the following members of the Department of Zoology, McGill University, to Dr. H. R. Scott who has gone through the manuscript and has given valuable suggestions, to Dr. J. Stanley for supplying me with his cultures of *Tribolium* and *Oryzaephilus* reared at controlled conditions of temperature and humidity in Autotrephon (Stanley, 1951), and to Mr. J. W. Pollock for taking photomicrographs. I also wish to express my gratitude to Professor E. Melville DuPorte, Department of Entomology, Macdonald College, Que., and to Dr. T. E. Mittler, Science Service Laboratory, Canada Department of Agriculture, St. Jean, Que., for their constructive criticism of the paper.

References

Auten, M. 1933. The structure of the digestive system in *Bolitotherus cornutus*. *Ohio Journal of Science* 33(4): 280-286.

Black, E. A. and R. T. Cotton. 1926. Biology of the saw-toothed grain beetle, *Oryzaephilus surinamensis* Linne. *J. Agric. Res.* 33: 435-452.

Brues, C. T., A. L. Melander and F. M. Carpenter. 1954. Classification of insects. Bull. Museum of Comparative Zoology, Harvard College, Cambridge, Mass. 108.

Carter, G. S. 1951. Animal Evolution. Sidgwick and Jackson Ltd., London.

Comstock, J. H. 1940. An introduction to Entomology. Comstock Publishing Company, Inc., Ithaca, New York.

Cotton, R. T. 1950. Insect pests of stored grain and grain products. Burgess Publishing Company, Minneapolis, Minnesota.

Fraenkel, G. and M. Blewett. 1944. Utilization of metabolic water. *Bull. Ent. Res.* 35: 127-139.

Good, N. E. 1935. The Flour Beetles of the genus *Tribolium*. Ph.D. thesis, George Washington University, U.S.A.

Grouvelle, A. 1912. Synonyms and descriptions of new genera and new types. (In French). Ann. Ent. Soc., France 81: 318-320.

Hinton, H. E. 1948. A synopsis of the genus *Tribolium* Macleay, with some remarks on the Evolution of its Species-groups (Coleoptera, Tenebrionidae). *Bull. Ent. Res.* 39: 13-56.

Hirsch, G. C. 1931. The Theory of fields of restitution, with special reference to the phenomena of secretion. *Biol. Rev.* 6: 86-131.

Howe, R. W. 1956. The biology of the two common storage species of *Oryzaephilus* (Coleoptera, Cucujidae). *Ann. appl. Biol.* 44(2): 341-355.

Krall, J. and D. T. Jones. 1943. Morphology of the digestive tract of *Cynaeus angustus* LeC., a Tenebrionid. Journal of Science, Iowa State College, 17: 221-225.

Lee, A. B. 1937. The Microtomist's Vade-mecum, 10th Ed., edited by J. B. Gatenby and T. S. Painter. P. Blakiston's Son and Co., Inc., Philadelphia.

Metcalf, C. L., W. P. Flint and R. L. Metcalf. 1951. Destructive and Useful Insects. 3rd Ed., McGraw-Hill Book Co., Inc., New York.

Michener, C. D. 1949. Parallelisms in the Evolution of the Saturnid Moths. *Evolution* 3(2): 129-141.

Miller, W. C. 1931. The alimentary canal of *Meracantha contracta* Beauv. (Tenebrionidae). *Ohio Journal of Science* 31(3): 143-156.

Mukerji, D. 1937. A note on section cutting of insects. Current Science, Indian Institute of Science, Bangalore, India 6: 16-2.

Mukerji, D. and R. N. Sinha. 1953. Effect of food on the life history of the flour beetle, *Tribolium castaneum* Herbst. *Jour. Kansas Ent. Soc.* 26(3): 118-124.

Noble, G. K. and M. E. Jaeckle. 1928. The digital pads of the tree frogs. A study of the phylogenesis of an adaptive structure. *J. Morph.* 45: 259-292.

Osborn, H. F. 1929. Titanotheres of Ancient Wyoming, Dakota and Nebraska. U.S. Dept. Int. Geol. Surv. Monogr., No. 55.

Pradhan, S. 1939. The alimentary canal and pro-epithelial regeneration in *Coccinella septempunctata* with a comparison of carnivorous and herbivorous Coccinellids. *Quart. Jour. Micr., Sc.* 81: 451-478.

Pradhan, S. 1937. Labial glands in Coleoptera. *Current Science* (India) 5: 590-591.

Prosser, C. L. 1950. Comparative Animal Physiology. W. B. Saunders Company, Philadelphia.

Roeder, K. D. 1953. Insect Physiology. John Wiley and Sons, Inc., New York.

Simpson, G. G. 1949. The meaning of Evolution. Yale University Press, New Haven, Connecticut.

Sinha, R. N. 1953. Sectioning insects with sclerotized cuticle. *Stain Technology* 28: 249-253.

Sinha, R. N. 1958. The alimentary canal of *Tribolium castaneum* Herbst (Coleoptera, Tenebrionidae). *Jour. Kansas Ent. Soc.* (in press).

Snodgrass, R. E. 1935. Principles of Insect Morphology. McGraw-Hill Book Co., Inc. New York.

Stanley, J. 1951. The autotrephon: an apparatus for rearing insects under controlled conditions with automatic time controlled withdrawal of samples. *Ecology* 32: 413-442.

Wigglesworth, V. B. 1953. The Principles of Insect Physiology. Methuen and Co., Ltd., London.

Yonge, C. M. 1937. Evolution and adaptation in the digestive system of the Metazoa. *Biol. Rev.* 12(1): 87-115.

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A Technique for Rearing Tyroglyphid Mites on Mould Cultures[1]

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This technique was developed to discover whether a tyroglyphid mite, *Tyrophagus castellanii* Hirst, was feeding on moulds growing on a food medium rather than on the food medium itself. Later on the technique was also found satisfactory for obtaining, under controlled temperature and humidity conditions, individual development records for all stages of the life-cycle of the mite.

Description of the Rearing Cell

Various types of microcells, such as that recommended by Jacot (1937) and later modified by Sengbush (1954) and those devised by Davis (1944), Robertson (1944), and Dr. T. Burnett of the Belleville laboratory, have been used by various authors for rearing non-predacious, non-parasitic mites. The type described below differs from those mainly by the addition of a partition that separates the food used from the mould growing on it so that the mites can feed on the mould only. The cell (Fig. 1) consists of two rectangular strips (B and D) of acrylic plastic, about one by three by one-sixteenth inches separated by a sheet of water-permeable cellophane (C), and covered on top with an ordinary microscope slide (A). The whole unit is bound together at each end by a strip of paper held with a small rubber band. A hole (E) in the form of a truncate cone and measuring one-quarter of an inch in diameter at the top and one-eighth of an inch at the bottom is cut through the plastic strip B at its centre. Painting the sides of the hole with ethylene chloride, which is a solvent of the plastic, helps to smooth the surface and eliminate any possible hiding place for the young larvae, and also facilitates cleaning. A second hole (F), about one-sixteenth of an inch in diameter, is drilled halfway through the centre of the second plastic strip D.

Assembling and Use of the Rearing Cell

In preparing a cell, the hole in the strip D is filled with powdered wheat germ made into a paste by adding the quantity of water necessary. Enough paste should be used to make up for the reduction in volume through evaporation. A sheet of water-permeable cellophane that has been soaked in water and pressed between the fingers to remove excess moisture is then placed over the plastic strip to cover the wheat germ. The strip B is carefully set in place on top of the cellophane with the holes on both strips directly over one another, so that they fit snugly at the edges and prevent the mites from getting trapped underneath. A gentle pressure on the top strip is sufficient to hold the pieces together. The cell is now ready for inoculating with mould. A fine needle is used to transfer spores from a culture of selected mould to the exposed surface of the moist cellophane. This is immediately covered with the microscope slide, and the whole unit is bound together as described above. After inoculation, the cage is placed in an incubator with controlled temperature and humidity. As the cell is not sealed air-tight and there is no method for measuring the humidity in such a small space, it is presumed that the humidity in the cell becomes similar to that in the incubator within a few hours, when any moisture condensed inside the cell has disappeared. The period required to obtain sufficient mould growth for mite infestation is about 24 hours. Then the cell is opened, the mites are placed in it with the point of a fine brush, and the cell is closed again immediately. A

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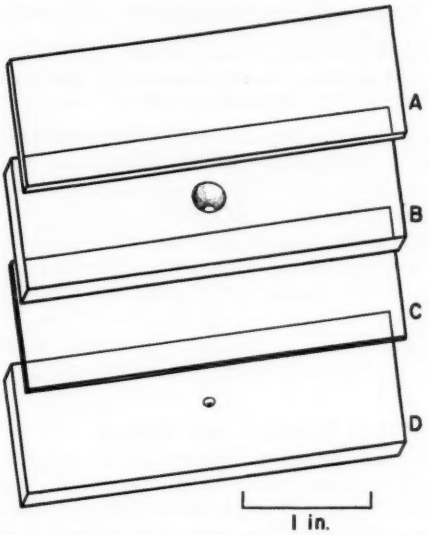

Fig. 1. Disassembled rearing cage: A, microscope slide; B, plastic strip; C, cellophane sheet; D, plastic strip.

dental nerve canal broach fitted into an ordinary entomological needle holder was satisfactory for handling the eggs.

Cells so prepared may be handled with a minimum of trouble and stacked in trays or holders in such a way as to occupy very little space in incubator or desiccator jars. They can be disassembled, cleaned, and used again indefinitely. Observations may be made rapidly and easily at any time with a low-power microscope. This type of cell has been used by the author for rearing mites individually and in pairs, but a much greater number of mites could probably be handled in a single container by enlarging it. With a fungus, *Aspergillus* sp., as food, several generations of *T. castellanii* were reared in this way.

Acknowledgments

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References

Davis, A. C. 1944. The mushroom mite (*Tyrophagus lintneri* (Osborn)) as a pest of cultivated mushrooms. *U.S. Dept. Agr. Tech. Bull.* 879.

Jacot, A. P. 1937. Culture of non-predacious, non-parasitic mites (Oribatoidea and Tyroglyphoidea). *In* Culture methods for invertebrate animals, ed. by P. S. Galtsoff *et al.*, pp. 245-246. Comstock Publishing Co., Ithaca, N.Y.

Robertson, P. L. 1944. A technique for biological studies of cheese mites. *Bull. Ent. Res.* 35: 251-255.

Sengbush, H. G. 1954. Studies on the life history of three oribatoid mites with observations on other species. *Ann. Ent. Soc. America* 47: 646-667.

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Development of Four Species of Aphids (Homoptera) on Potato[1]

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In Eastern Canada four species of aphids, *Macrosiphum solanifolii* (Ashm.), *Myzus persicae* (Sulz.), *Aulacorthum solani* (Kltb.), and *Aphis abbreviata* Patch infest potatoes. Since 1953 it has been possible to rear the four species in the greenhouse throughout the year (MacGillivray, 1955).

The life-histories of these species have been discussed by Patch (1925). The asexual phase of *M. persicae* has been studied by Horsfall (1924), Weed (1927), Bonnemaison (1951), and Sylvester (1954), and that of *M. solanifolii* by Smith (1919).

Between March and October, 1954, the four species were reared in the greenhouse at Fredericton, and this is a report of detailed records of their development from birth to death.

Materials and Methods

M. persicae was obtained from cultures of asexual females maintained on swede turnip in the greenhouse since 1939. Before the experiment about 300 aphids were transferred to potato leaves to avoid the change from one host to another during the experiment. The other species were obtained from cultures of asexual females maintained since 1953 on Katahdin potatoes in the greenhouse. All cultures were confined in copper screen cages (MacGillivray and Anderson, 1957).

The aphids were reared individually on excised leaves of Katahdin, in four-inch pots, each pot covered with an organdy cage as described by MacGillivray and Anderson (1957). At the beginning of the experiment one adult was placed on each excised leaf, and after ten hours the adult and all but one of the nymphs produced were removed. This eliminated handling the first-instar nymph, which is easily injured. One hundred nymphs of each species were retained, one nymph on each of 100 leaves. The aphids were examined every 24 hours and records made of the durations of instars, reproductive period, and life, and also of the number of offspring produced. The leaves were replaced every three or four days depending on their condition, and the aphids were transferred to the new leaves by means of a camel's-hair brush moistened with water (experience had shown that young nymphs transferred with a brush moistened with saliva often die). Some aphids were lost or accidentally killed. The data from these were used for those stages of development that were completed.

Although each species molts four times, the aphids were not considered to be mature until they had reproduced. The period between the last molt and maturity was called the fifth instar.

Temperature and humidity were not constant although the temperature control was set to keep the chamber at 70°F. Fluctuations occurred because of the sun and other uncontrollable factors. A planimeter was used to measure the area beneath each temperature curve on the thermograph sheets. This area was converted to the average temperature. Two fluorescent lights of 120 watts each placed 3 feet above the greenhouse bench operated 18 hours each day from 5 a.m. to 11 p.m., supplementing natural daylight. Light intensity varied with solar radiation.

Since 100 aphids of each species were too many to be studied at the same

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TABLE I

Ranges and mean duration (days) of various stages of development, and fecundity, of apterous and alate forms of *Macrosiphum solanifolii* (Ashm.) in the greenhouse at an average temperature of 71.2°F., March 24 to May 16, 1954

Stage	Apterous			Alate		
	Range	Mean	No. of aphids	Range	Mean	No. of aphids
Instar I	1–2	1.7± .12*	16	1–4	1.8± .10*	50
II	1–3	1.9± .13	16	1–3	1.8± .07	50
III	1–4	2.1± .15	16	1–3	2.0± .08	50
IV	1–3	2.4± .18	16	1–5	3.0± .13	50
V	1–3	1.5± .20	16	1–5	1.8± .11	50
Birth to maturity	8–11	9.7± .14	34	9–13	10.6± .11	60
Reproductive period	16–28	19.8± .66	26	9–27	22.0± .47	44
Offspring per aphid	48–81	67.3±1.6	26	26–88	64.1±1.8	42
Final reproduction to death	4–24	14.5±1.2	25	2–22	11.3± .78	48
Longevity	36–51	44.8± .97	25	32–53	44.2± .08	37

*Standard error.

time, *M. solanifolii* was observed between March 24 and May 16, *M. persicae* between May 17 and July 5, *A. abbreviata* between July 6 and August 24, and *A. solani* between August 25 and October 20. Most of *M. solanifolii* were alate forms. The other species were apterous.

Macrosiphum solanifolii

Of the four potato-infesting species, *M. solanifolii* is the easiest to rear and study. The first-instar nymph is about as large as the third-instar nymph of the other species and the cast skins are easily located. Since it is not possible in the first instar to determine, at least macroscopically, whether an aphid will be winged, a mixture of alate and apterous forms was reared, two-thirds of which became winged. Table I summarizes the results for this species. After the final molt alatae produced young as soon as did apterae. Both forms produced about the same number of nymphs during the reproductive period. Student's *t* test showed that the following differences were significant: In alatae the maturation period was one day longer ($P<.001$) than in apterae, the reproductive period two days longer ($P<.01$), and the time from final reproduction to death three days shorter ($P<.02$).

Fig. 1 shows that apterae produced the greatest number of young on the ninth day of reproduction and alatae on the fifth day. Apterae generally produced more nymphs daily than did alatae until the thirteenth day of reproduction. Between the thirteenth and twentieth day alatae produced more nymphs than did apterae. The largest number of nymphs produced by an aptera in one day was ten, on the fifth day, and by an alata, eleven, on the fourth day. In both forms at least one-half of the total progeny had been produced by the tenth day.

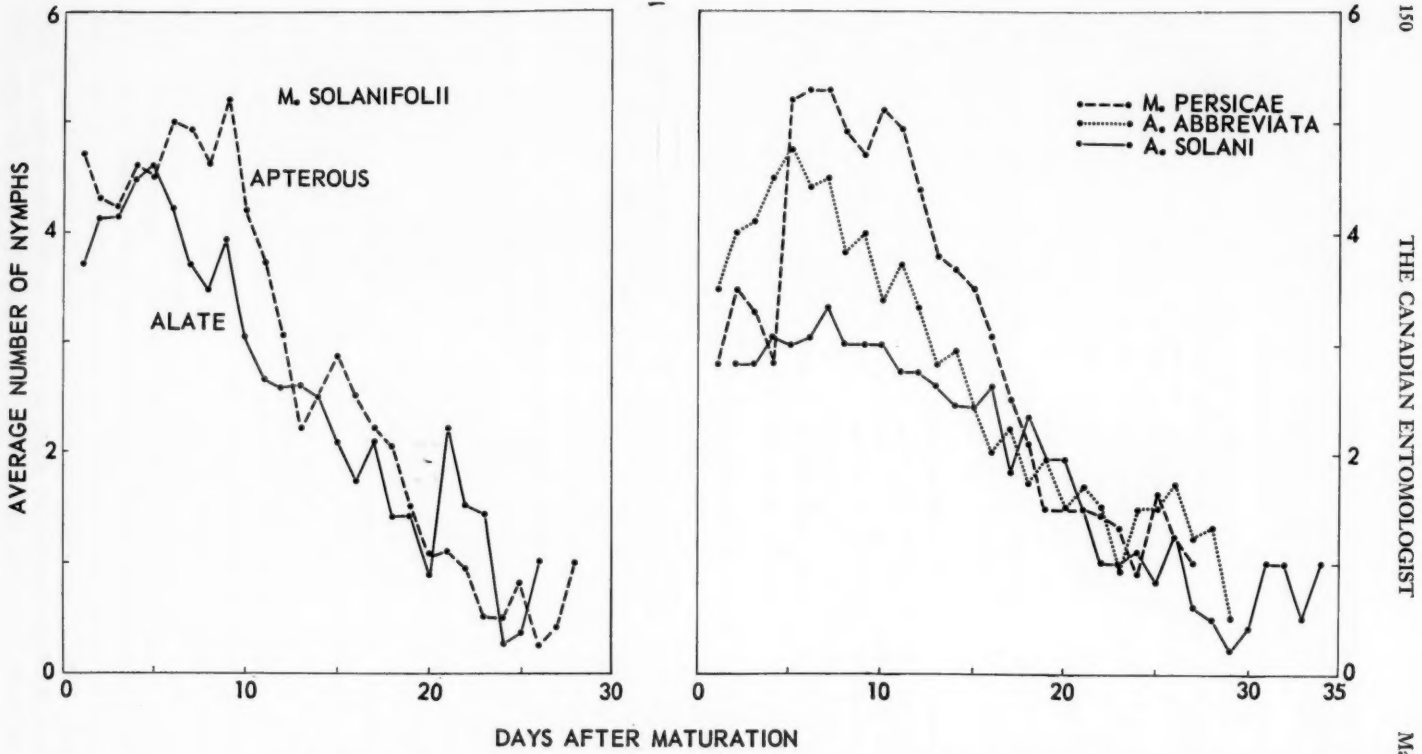

Fig. 1. Average number of aphids produced daily by each of four species maintained on excised potato leaves. *Macrosiphum solanifolii* based on 32 wingless and 59 winged aphids from March 24 to May 16, 1954; *Myzus persicae* on 61 aphids from May 17 to July 5, 1954; *Aphis abbreviata* on 41 aphids from July 6 to August 24, 1954; and *Aulacorthum solani* on 31 aphids from August 25 to October 10, 1954.

TABLE II

Ranges and mean durations (days) of various stages of development, and fecundity, of *Myzus persicae* (Sulz.) in the greenhouse at an average temperature of 68.2°F., May 17 to July 5, 1954

Stage	Range	Mean	No. of aphids
Instar I	1–4	2.4± .14*	32
II	1–3	1.8± .12	32
III	1–3	2.0± .12	32
IV	1–4	2.1± .13	32
V	1–2	0.7± .10	32
Birth to maturity	7–11	9.1± .07	96
Reproductive period	15–27	20.1± .43	61
Offspring per aphid	47–103	75.5±1.30	61
Final reproduction to death	5–23	13.9± .60	58
Longevity	20–52	41.1± .70	60

*Standard error.

B. Johnson (1953) showed that in *Aphis fabae* Scop. a relationship exists between the number of nymphs produced immediately after maturity, the ability to fly, and muscle autolysis and found that *A. fabae* loses its ability to fly after the production of 12 to 18 nymphs. C. G. Johnson (1954) believes that aphids show no inclination to fly during a teneral period of a few hours after the final molt but fly off readily when mature for flight. In this experiment it was not observed that *M. solanifolii* attempted to fly and both apterous and alate forms produced offspring about 1½ days after the final molt. Apterae produced about five nymphs on the first day but produced less than this each day until the sixth day. However, alatae continued to produce more nymphs daily than their initial production until the eighth day. This increase in daily reproduction by alate forms of *M. solanifolii* may be related to the lack of flight by these alate forms. If it performs in the same manner as *A. fabae* it would lose the ability to fly in about 4 days, based on its production of nymphs. Had it flown prior to this the recorded increase in nymphal production over the initial reproduction may not have occurred.

Smith (1919) reared this species on egg-plant from March 20 to May 30 out-of-doors at Norfolk, Virginia, where it reproduces asexually throughout the year. At Fredericton the aphids matured sooner, reproduced more offspring over a longer period, lived longer after final reproduction, and had a longer life than those at Norfolk.

Myzus persicae

Table II summarizes the records of *M. persicae*. Fig. 1 shows that the greatest number of offspring was produced between the fifth and seventh days and that by the tenth day about one-half of the total had been born. Between the fifth and tenth days an average of five nymphs per day were produced.

Horsfall (1924) at Bustleton, Weed (1927) at Madison, and Sylvester (1954) at Berkeley reared this species on cabbage, spinach, and sugar beet respectively.

TABLE III

Ranges and mean durations (days) of various stages of development, and fecundity, of *Aphis abbreviata* Patch in the greenhouse at an average temperature of 67.4°F., July 6 to August 24, 1954

Stage	Range	Mean	No. of aphids
Instar I	1–4	1.9± .11*	35
II	1–4	1.9± .11	35
III	1–3	1.4± .10	35
IV	1–4	1.7± .06	35
V	1–2	0.3± .44	35
Birth to maturity	6–11	7.2± .09	33
Reproductive period	4–30	20.3± .93	87
Offspring per aphid	10–93	63.9±2.9	41
Final reproduction to death	3–22	11.3±1.2	30
Longevity	12–48	35.9±1.5	41

*Standard error.

Horsfall's work was conducted in an insectary where seasonal variations in temperature occurred. Weed and Sylvester reared the species at average temperatures of 72.8°F. and 72°F. respectively. The time required to reach maturity was shorter at Berkeley and Madison than at the other localities. Fecundity at Fredericton was similar to that at Berkeley and much greater than at Madison or Bustleton. The reproductive period and longevity were longest at Fredericton. In all cases the Fredericton results were based on more specimens. The differences may be due to factors such as temperature and humidity as discussed by Horsfall (1924) and Weed (1927), and to the host plants.

Aphis abbreviata

This is the most difficult of the aphids to handle, because of its small size; and to rear, since it readily produces sexuales in the greenhouse when temperature and photoperiod are not suitably regulated (MacGillivray, 1955). Table III shows that *A. abbreviata*, unlike the other species, generally reproduced on the day of the last molt. Fig. 1 shows that an average of four nymphs were produced daily for the first eleven days, the greatest number being produced on the fifth day. By the tenth day one-half of the total had been produced.

Aulacorthum solani

A. solani is easy to rear in the greenhouse and is not as restless as the other species. In the experimental cages many of the adults and nymphs congregated at the base of the midrib, near the surface of the water in the vial. Possibly this species prefers a more humid environment or finds this tissue more suitable.

Table IV shows that the fifth instar of this species may last as long as six days. Fig. 1 shows that an average of three nymphs were produced daily for the first ten days of reproduction, the greatest number being produced on the seventh day. By the tenth day one-half of the total progeny had been born.

Comparison of Species

Although each species was reared at a different time and the light intensity varied somewhat, the following comparisons may be noted. Apterous forms of *M. persicae* and *M. solanifolii* were similar in development. They reproduced for the same period, 20 days, and lived for about the same length of time after final reproduction. Although they matured in about the same length of time, 9 days, and had about the same longevity, 41 to 44 days, the differences are statistically significant; however, these seem to be too small to be of any practical significance.

A. abbreviata and *A. solani* had few similarities to the other species or to each other. *A. abbreviata* was mature in 7 days and *A. solani* in 12 days. However, in all species the reproductive period was more than twice as long as the maturation period. *A. solani* reproduced at least five days longer than the other species, which reproduced for about the same length of time. *A. abbreviata* produced about the same number of nymphs as *M. solanifolii* and *A. solani* but *M. solanifolii* produced more nymphs than *A. solani* ($P.<.02$). *M. persicae* produced the greatest number of nymphs, and generally more nymphs daily from the fifth to the seventeenth day of reproduction. During the first eleven days of reproduction, apterous forms of *M. solanifolii* generally produced more nymphs daily than did *A. abbreviata.* Each of the four species had produced at least one-half of its progeny by the tenth day. In each species the peak in reproduction occurred between the fifth and tenth days. *M. persicae* showed the greatest fluctuation in daily reproduction until it reached the peak and the least fluctuation after the peak. These records suggest that if the four species became established in equal numbers out-of-doors on potatoes, *M. persicae* would become the most abundant, followed by *M. solanifolii*, *A. abbreviata*, and *A. solani.* This is essentially what the authors have observed in New Brunswick in areas where parasitism and predation do not occur early.

TABLE IV

Ranges and mean durations (days) of various stages of development, and fecundity, of *Aulacorthum solani* (Kltb.) in the greenhouse at an average temperature of 72.6°F., August 25 to October 10, 1954

Stage	Range	Mean	No. of aphids
Instar I	1–6	2.4± .18*	37
II	1–3	1.8± .10	37
III	1–5	2.4± .21	37
IV	1–7	2.7± .23	37
V	1–6	3.2± .24	37
Birth to maturity	9–20	12.7± .17	91
Reproductive period	15–34	25.8± .69	32
Offspring per aphid	25–81	60.3±1.8	31
Final reproduction to death	3–23	8.9± .99	29
Longevity	27–57	45.7±1.1	32

*Standard error.

After reproduction had ceased, *M. solanifolii* and *M. persicae* lived 14 days and *A. solani* and *A. abbreviata* about ten days. *A. abbreviata* had the shortest life. During the non-reproductive period before death all species appeared to feed but had a tendency to wander. This may be significant in relation to the spread of certain viruses. If wandering aphids should feed for a short period on an infective plant and then move to a new plant and feed they may transmit disease. Bradley (1954) pointed out that it was during brief feeding punctures into infected plants that *M. persicae* became infective with virus Y, and later (1956) noted that a starved aphid makes a few brief attempts to feed before it settles at one site. Furthermore, if *M. persicae* had fed on plants infected with potato leaf roll virus, during the wandering period it could infect another plant, if it fed for at least 12 hours for MacCarthy has shown that, when fed for at least five days on infected plants, *M. persicae* could transmit potato leaf roll virus as long as it lived.

Fernow and Kerr (1953) treated potato-infesting aphids as a homogeneous population not distinguishing among species of aphids in the experiment. Sylvester (1949), Sylvester and MacLean (1949), and Pond, Adams, and Moore (in preparation) have noted that all potato-infesting aphids do not react in the same way to certain insecticides. We have shown that there are differences among potato-infesting aphids in their maturation period, reproductive capacity, and longevity. In addition, in *M. solanifolii* differences other than morphological exist between apterous and alate forms. In future, consideration should be given to the individual species of a population rather than to a population of aphids infesting potato. It may also be necessary to consider what portions of a population of a species are made up of apterous or alate forms.

Summary

The maturation period, reproductive period, longevity, and fecundity of four species of potato-infesting aphids, *Macrosiphum solanifolii* (Ashmead), *Myzus persicae* (Sulzer), *Aphis abbreviata* Patch, and *Aulacorthum solani* (Kltb.), reared from birth to death on excised leaves of potatoes, between March and October, 1954, are recorded. Apterous forms of *M. persicae* and *M. solanifolii* developed similarly while *A. abbreviata* and *A. solani* differed from each other and from the other species. In all species the reproductive period was more than twice as long as the maturation period and the peak of reproduction occurred between the fifth and tenth days. *M. persicae* produced the greatest number of nymphs and *A. abbreviata* had the shortest life. During the non-reproductive period before death all species appeared to feed but had a tendency to wander. Feeding during this period may have a significance in the spread of certain virus diseases of potato. It is suggested that in aphid studies the species involved and its form, alate or apterous, should be considered individually, rather than considering potato-infesting aphids as a homogeneous population.

References

Bonnemaison, L. 1951. Contribution à l'étude des facteurs provoquant l'apparition des formes ailées et sexuées chez les Aphidinae. *Thèses Sci. Nat., Univ. Paris, Ser. A*, 2401, No. 3273.

Bradley, R. H. E. 1954. Studies of the mechanism of transmission of potato virus Y by the green peach aphid, *Myzus persicae* (Sulz.) (Homoptera: Aphidae). *Canadian J. Zool.* 32: 64-73.

Bradley, R. H. E. 1956. Effects of depth of stylet penetration on aphid transmission of potato virus Y. *Canadian J. Microbiology* 2: 539-547.

Fernow, K. H., and S. H. Kerr. 1953. Leafroll control by use of insecticides. *American Potato J.* 30: 187-196.

Horsfall, J. L. 1924. Life history studies of *Myzus persicae* (Sulzer). *Pennsylvania Agr. Expt. Sta. Bull.* 185.

Johnson, B. 1953. Flight muscle autolysis and reproduction in aphids. *Nature* 172: 813.
MacCarthy, H. R. 1954. Aphid transmission of potato leafroll virus. *Phytopathology* 44: 167-174.
MacGillivray, M. E. 1955. A method of rearing potato infesting aphids throughout the year in the greenhouse. *American Potato J.* 32: 67-68.
MacGillivray, M. E., and G. B. Anderson. 1957. Three useful insect cages. *Canadian Ent.* 89: 43-46.
Patch, E. M. 1925. Potato aphids. *Maine Agr. Expt. Sta. Bull.* 323.
Pond, D. D., J. B. Adams, and C. A. Moore. Reactions of four species of potato-infesting aphids to two insecticides In preparation.
Smith, L. B. 1919. The life history and biology of the pink and green aphid (*M. solanifolii*, Ashmead). *Virginia Truck Expt. Sta. Bull.* 23.
Sylvester, E. S. 1949. Aphid control experiment on potatoes in California—with special reference to the selective action of DDT dusts. *J. Econ. Ent.* 42: 766-769.
Sylvester, E. S., and J. G. McLean. 1949. Aphid control on potatoes. *American Potato J.* 26: 16-24.
Sylvester, E. S. 1954. Insectary life history and apterous morphology of *Myzus persicae* (Sulzer) (Homoptera, Aphidae). *Ann. Ent. Soc. America* 47: 397-406.
Weed, A. 1927. Metamorphosis and reproduction in apterous forms of *Myzus persicae* Sulzer as influenced by temperature and humidity. *J. Econ. Ent.* 20: 150-157.

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Two New Species of *Ceraticelus* (Araneae: Erigonidae) from Western North America[1]

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Crosby and Bishop (1925) published a comprehensive revision of the New World genus *Ceraticelus*, and from time to time other species have been described as they appeared. The following descriptions of two additional species were based upon specimens in the American Museum of Natural History in New York. All type material was deposited in that institution.

Ceraticelus berthoudi new species

Figs. 1, 3, 8, 11

Male.—Total length about 1.5 mm.; cephalothorax 0.7 mm. long and 0.6 mm. wide; carapace orange-brown, the cephalic lobes dusky to black; a dark mark behind the posterior cephalic lobe along the middle line; sternum orange-yellow, broadly margined with black; legs yellow, suffused with grey; abdomen dark grey except that the sclerites are orange-grey; epigastric, inframammillary, and dorsal sclerites present.

Carapace, viewed from above, broadly and evenly rounded along the sides toward the front, with a shallow constriction in the margin immediately behind the level of the posterior lateral eyes (Fig. 11); viewed from the side, rather steeply ascending from behind, but level from the thoracic groove to the base of the posterior cephalic lobe (Fig. 8); cephalic lobes large, constricted at the bases; posterior lobe round in dorsal view; anterior smaller than the posterior, protruding forward greatly, with about two-thirds of its length visible from above.

Palpus with a very broad tibial apophysis (Fig. 3), the lateral tooth on this apophysis drawn out long and slender and about half as long as the distal tooth; distal tooth long, evenly curved to the tip; tip not hooked.

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Female.—Total length about 1.7 mm., cephalothorax 0.7 mm. long and 0.6 mm. wide; carapace, sternum, and legs coloured as in the male; eye region black; abdomen grey, without conspicuous tubercles at the hair bases; epigastric and inframammillary sclerites present, dorsal sclerite absent; epigynum as in Fig. 1.

Diagnosis.—This species is very similar in colouration to *C. rowensis* Levi and Levi, found at high mountain altitudes in Alberta (Levi and Levi, 1955). It is separated from that species by the shape of the cephalic lobes and the tibial apophysis of the male, and by the structure of the epigynum in the female. It is separated from *C. bulbosus* (Em.) by its dark body colour, as well as by structural characters. Illustrations of the carapace of the male of *rowensis* (Fig. 13), and of the male palpal tibiae of *rowensis* (Fig. 4) and *bulbosus* (Fig. 2), are provided for purposes of comparison.

Type Locality.—Berthoud Pass, Clear Creek County, Colorado.

Type Material.—Holotype male. Allotype female. Paratypes: 1 male and 1 female. All from the type locality, Aug. 24, 1935 (W. Ivie).

Ceraticelus silus new species

Figs. 5, 9, 10, 12

Male.—Total length 1.5 to 1.7 mm.; cephalothorax 0.7 mm. long and 0.5 mm. wide; carapace pale orange-yellow, the cephalic lobes dusky; a dark mark behind the posterior cephalic lobe along the middle line; sternum yellow, margined with grey; legs yellow, lightly suffused with grey; abdomen dark grey to black except that the sclerites are yellowish, heavily suffused with grey, and rather indistinct; epigastric, inframammillary, and dorsal sclerites present.

Carapace, viewed from above, evenly rounded toward the front, with a long, shallow constriction in front of the middle, and broadly convex in front (Fig. 12); viewed from the side, steeply ascending from behind in a slightly convex curve to the base of the posterior cephalic lobe (Fig. 9); posterior cephalic lobe about three-fourths as broad as the anterior lobe, slightly constricted at the base, and longer than broad; anterior lobe protruding well forward, not separated from the "clypeus" by a basal constriction, not concealed from above by the posterior lobe.

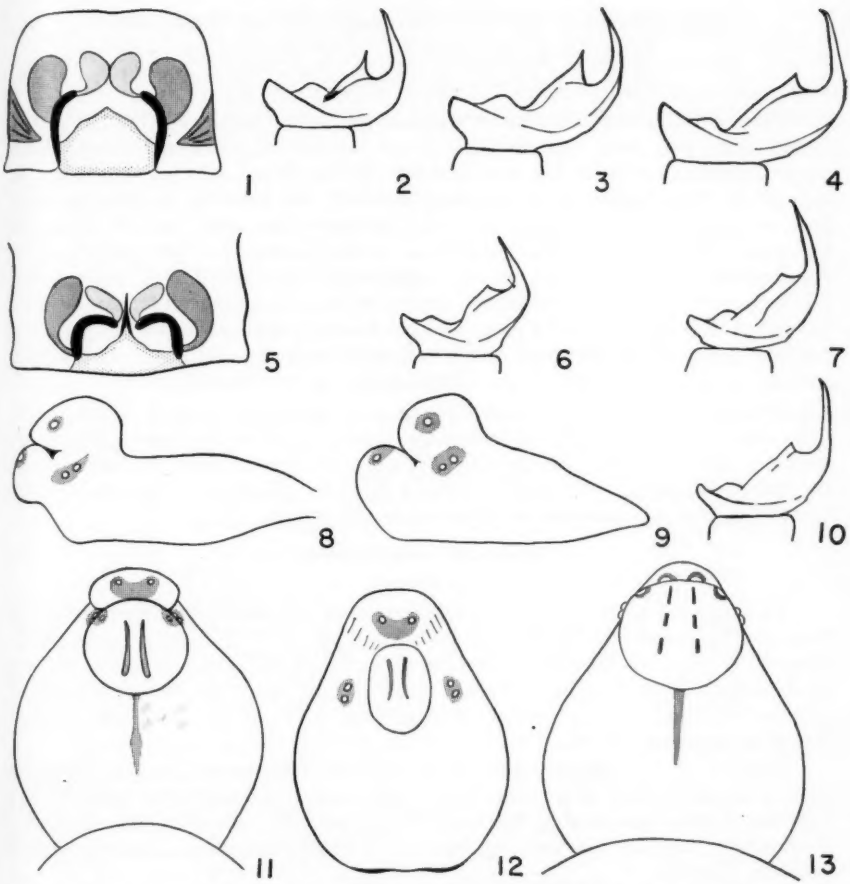
Palpus with a relatively long, slender tibial apophysis; the lateral tooth short and conical, the distal tooth long, with only a slight curve inward and with a very slight hook at the tip (Fig. 10).

Female.—Total length about 1.7 mm.; cephalothorax 0.7 mm. long and 0.6 mm. wide; carapace, sternum, and legs coloured as in the male; eye region and upper half of "clypeus" black; abdomen dark grey to black except that the sclerites are brown; epigastric and inframammillary sclerites present, dorsal sclerite absent; epigynum as in Fig. 5. "Clypeus" broadly convex, the eyes not in profile.

Diagnosis.—This species is very similar in colouration to *C. atriceps* (O.P.-Cambridge), although the abdomen is usually paler in the latter. It is distinct from *atriceps* in the shape of the cephalic lobes and the tibial apophysis of the male, and in the structure of the epigynum of the female. It is separated from *C. alticeps* (Fox) by its dark body as well as by structural characters. Illustrations of palpal tibiae of *atriceps* (Fig. 7) and *alticeps* (Fig. 6) are provided for purposes of comparison.

Type Locality.—Southeast Wrangell, Alaska.

Type Material.—Holotype male. Allotype female. Paratypes: 3 males and 4 females. All from the type locality, Sept. 1-20, 1951 (B. Malkin). The name *silus* was chosen for this species because of the broadly convex "clypeal" region of the carapace in both sexes.



Figs. 1-13. *Ceraticelus* spp. 1, 5. Epigyna of females. 1, *C. berthoudi*. 5, *C. silus*. 2-4, 6, 7, 10. Palpal tibiae of males. 2, *C. bulbosus*. 3, *C. berthoudi*. 4, *C. rowensis*. 6, *C. alticeps*. 7, *C. atriceps*. 10, *C. silus*. 8, 9, 11-13. Carapaces of males. 8, *C. berthoudi*. 9, *C. silus* (lateral view). 11, *C. berthoudi*. 12, *C. silus*. 13, *C. rowensis* (dorsal view).

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References

Crosby, C. R., and S. C. Bishop. 1925. Studies in New York spiders. Genera: *Ceratinella* and *Ceraticelus*. New York State Mus. Bull. 264. 71 pp.

Levi, Lorna R., and H. W. Levi. 1955. Spiders and harvestmen from Waterton and Glacier national parks. *Can. Field-Nat.* 69: 32-40.

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Observations on the Development of Crickets

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The house cricket, *Acheta domesticus* (L.) (Gryllidae, Orthoptera), is a cosmopolitan and easily available insect, and is most suitable as a test animal for physiological research, as has been pointed out by Stone (1953). However, in spite of the long familiarity of entomologists with this insect it has received very little attention in the literature, no doubt because it has never been of economic importance in Europe or North America. Such quantitative observations on its development as do exist are rather fragmentary (Kemper, 1937; Stone, 1953; Busvine, 1955). The present article describes, in a somewhat more precise way, the rate of development of the nymph of the house cricket at various temperatures and the number and duration of the nymphal stadia, as well as a satisfactory method of rearing the insect and observations on its fecundity.

Observations on two hitherto little-known species of crickets, which are in some respects more suitable as laboratory animals than is the house cricket, are included: these are *A. configuratus* (Walk.), recorded from the Indian subcontinent (Chopard, 1936) and *Gryllodes sigillatus* (Walk.), which has a widespread tropical and subtropical distribution (Blatchley, 1920).

Materials and Methods

1. Insects

The original adults of a 'Canadian' strain of *A. domesticus* were collected from the basements of Macdonald College. Eggs of a 'Pakistani' strain of *A. domesticus* were obtained from females collected in the outbreak areas of Usta Muhammad, West Pakistan. These strains, which are reproductively isolated (Ghouri and MacFarlane 1957a), will be referred to as *A. domesticus* (Can.) and *A. domesticus* (*Pak.*).

Eggs of *A. configuratus* were obtained from females collected in the same locality as those of *A. domesticus* (*Pak.*) and those of *G. sigillatus* from females collected from residences in Karachi, West Pakistan. All Pakistani specimens were kindly supplied by the Department of Plant Protection, Government of Pakistan, Karachi.

Dr. A. B. Gurney of the U.S. National Museum, Washington, D.C., very kindly confirmed the writers' identifications.

2. Rearing

Stone (1953) and Busvine (1955) describe methods for rearing crickets which are quite adequate but for reasons of convenience and equipment at hand we have adopted rather different methods.

All stock and experimental animals were reared in incubators fitted with thermostats which controlled the temperature to within $\pm 1°C$. Humidity was maintained at $50 \pm 5\%$ R.H. using saturated salt solutions (O'Brien, 1948).

(a) Maintenance of Adults

Adults were kept in one-gallon candy jars with 10 to 12 adults per jar. An inverted shell vial of 32 ml. capacity, tightly plugged with cotton wool which was covered with a piece of filter paper, served as a satisfactory source of water for about ten days. Females very rarely oviposited in the cotton, and only when oviposition dishes (see below) were not provided. The surface area of the jar was increased with strips of folded paper towelling.

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Crickets cannot survive long without either a source of free water or food of high water content. Where water is provided, they will readily take a dry diet. They will survive, more or less successfully, on many varieties of cereals, oil seeds, fresh or dry vegetable and animal matter. Preliminary trials showed that the following diet* was best for nymphal development, and it was used in the present studies:

1. Ground wheat, 2 parts.
2. Ground oat groats, 3 parts.
3. Skim milk, 37 parts.
4. Fish meal, 20 parts.
5. Brewer's yeast, 5 parts.
6. Cane molasses, 10 parts.
7. Corn oil, 5 parts.
8. Vitamin, mineral and antibiotic supplement, 3 parts.

Total ..... 85 parts.

The vitamin, mineral and antibiotic supplement contained the following materials:

1.	Iodized salt	124.0 mg.
2.	Bone flour	645.0 mg.
3.	Ferrous sulphate	36.0 mg.
4.	Vitamin B_{12} plus penicillin	70.0 mg.
5.	Cr O_3	72.5 mg.
6.	Vitamin B_2	0.13 mg.
7.	Vitamin B_6	0.13 mg.
8.	Ca pantothenate	0.26 mg.
9.	Vit.A. (250,000 I.U.)	1.16 mg.
10.	Vitamin D_2	38.5 mg.

'Baby rabbit pellets', sold by Ogilvie Flour Mills Co. Ltd., Montreal, later proved to be a better diet.

Food was placed in round plastic lids (diam. 1½") or on trays of strong, non-absorbent paper. The feeding dishes must be large enough to ensure free access without overcrowding.

(b) Provision for Oviposition

Gravid females will oviposit on any soft, moist surface on which they can obtain footing and insert their ovipositors. Stone (1953) obtained eggs in a two-inch layer of moist sand spread on the floor of the rearing jar. Busvine (1955) recommended the use of moist cotton pads. Both methods are satisfactory for the purpose of general rearing, but are not convenient for determining fecundity or for obtaining large numbers of eggs of a known age. We used oviposition dishes and found them very satisfactory for our purposes. Round plastic lids 2" in diameter were filled with a half-inch layer of fine sterilized sand (later we used jam cups to get a deeper layer of sand) and the sand just moistened. Browning (1952) similarly used trays of moist sand to obtain eggs.

Eggs were obtained by supplying dishes to a batch of gravid females on alternate days, as a matter of convenience. The water tubes were removed from the jars to attract females promptly to the dishes: in search of water females congregated on the dish and thus discovered a suitable site for oviposition.

The fact that females will not deposit eggs until they find a suitable substrate, together with the fact that eggs are not fertilized until they are being deposited, made it possible to obtain a large supply of eggs of the same age within a few

*Obtained from the Department of Nutrition, Macdonald College.

hours, by simply withholding the dishes when eggs were not required; very few eggs were deposited in the cotton used for watering. Females of *A. domesticus* and *G. sigillatus* spent some time in becoming familiar with the oviposition dishes, whereas females of *A. configuratus* laid eggs shortly after the dishes were placed in the jar. Egg dishes were usually left with the females for about 12 hours, a group of ten females normally laying about a thousand eggs in this time.

Precautions had to be taken to keep the adult cultures in darkness. For several weeks we used an incubator which had an electric lamp in the heating circuit, and during this period a very low percentage of the eggs hatched, and those eggs that did not hatch showed no development. Apparently the flashing light prevented copulation, as virgin females were added to the cultures during this period.

(c) Incubation of Eggs

Egg dishes containing eggs were emptied on a paper towel (from which the newly-emerged hoppers could be easily removed with an aspirator) and towel and sand were placed in an air-tight jar containing a small pad of moist cotton to ensure 100% atmospheric humidity. Excess moisture had to be avoided, since it condensed on the sides of the jar and trapped the newly-emerged hoppers. The optimal temperatures for the development of the eggs are about the same as those of the hoppers; a report on the temperature and water relations of the egg is in preparation (Ghouri and McFarlane 1957b).

(d) Fecundity

All adults were obtained from hoppers reared at 28°C. The females were removed from the rearing jars and paired singly with males of the same stock within 24 hours of their becoming adult. Each pair was kept in a two-pound ointment jar provided with food and water. The oviposition dishes were placed in the jars on alternate days until the female died. The dishes in each jar were removed after 24 hours and the eggs counted.

(e) Rearing of Nymphs

All hoppers emerging from a batch of eggs within 24 hours were divided into groups of 10 each and liberated in two-pound ointment jars containing food, a water tube and a strip of folded paper, and covered with muslin to prevent escape of the hoppers. The development of hoppers from any one batch was studied at three different temperatures and at least 30 hoppers were kept at each temperature. Hoppers of the Canadian strain were in all experiments reared at 35°C. as a control.

Strips of folded paper towelling about an inch wide provided good resting and moulting places. The cannibalism which occurred if hiding places were not provided, even when food was abundant, was thereby much reduced, if not eliminated.

As soon as the hoppers started becoming adult they were removed from the jars and their sex and number were recorded, daily at temperatures of 28, 33 and 35°C., and on alternate days at 23 and 38°C.

The humidity in the incubator, though not in the rearing jar, at all temperatures was 50± 5% R.H. This humidity was chosen since it was the lowest at which no clustering of the insects around the water source was observed, and it was thought that a rather dry environment more closely approximated the natural conditions under which the insect lives than a moist one. There was also no danger of food spoilage at this dry humidity. The effect of humidity on the insects was not studied, at least in a direct way, since precise humidity effects

are difficult to determine in cases where the insect must be given a source of free water or moist food.

(f) Number and Duration of Nymphal Stadia

In order to determine the number and duration of the stadia, the hoppers of the three species were carefully observed from eclosion to the adult stage.

In single rearing, which was carried out with the hoppers of *A. domesticus* (*Can.*) at 28° and 35°C., the thorax and head were marked with India ink soon after emergence and at each successive moult. As a check, after every moult, the rearing jar was emptied on white paper and the contents thoroughly examined. The old cuticle of the mandibles and head capsule was always found although the rest of the exuviae had usually been consumed.

The observations made during single rearing showed that at 35°C. the hoppers generally moulted every three days until the appearance of the wing pads. Therefore, in the case of group rearing, observations were repeated three days after each moult. In the light of experience gained during the single rearing, the newly moulted hopper, because of its light color and extended abdomen, could be readily detected, and the procedure of marking was therefore abandoned.

In order to determine the minimal duration of the nymphal stadia of each species at 35°C., 50-100 newly-emerged hoppers were divided into two groups of ten each and each group was reared in a two-pound jar. Three days after emergence, these jars were examined and the hoppers which had moulted were separated from the rest and carried on in groups of ten or less in another jar. This was repeated every third day until the hoppers became adult.

Results

Mean fecundity values are presented in Table I. The mean duration of nymphal life and survival of the two strains of *A. domesticus* are presented in Table II; similar figures for *G. sigillatus* and *A. configuratus* are presented in Tables III and IV. The duration and number of nymphal stadia of *A. domesticus* (*Can.*) as determined by single rearing are shown in Table V. The minimal duration of the nymphal stadia is shown in Table VI.

Females of *A. domesticus* (*Can.*) developed more rapidly than males ($P<0.01$) at 23, 28, 33 and 35°C.; at 38 and 41°C. differences were not apparent but mortality was very high (90%); both males and females developed most rapidly at 35°C. ($P<0.01$). Females of *A. domesticus* (*Pak.*) developed more rapidly than males at 33°C. ($P<0.01$) and at 35°C. ($P<0.05$); there was no significant difference in rate at 23 and 28°C.; mortality was high at 38 and 41°C.

TABLE I

Mean fecundity values

Species	Temp. (°C.)	No.	Pre-oviposition Period (days)	Oviposition Period (days)	Post-oviposition Period (days)	Longevity (days)	No. of Eggs Laid
A. domesticus (*Can.*)	28	6	10	35	19	64	728
	35	3	5	36	16	57	1060
A. configuratus	28	6	8	36	7	51	667
G. sigillatus	28	6	9	44	8	61	864

(73, 83%). Females of *G. sigillatus* developed more rapidly than males at 33 and 35°C. ($P<0.01$), but there was no significant difference at 28°C.; development of each sex was most rapid at 35°C. ($P<0.01$). With *A. configuratus*, there was no significant difference ($P>0.05$) between development of males and females at 28, 33 and 35°C., but the males developed more rapidly at 23°C. ($P<0.05$). Only 51% of the hoppers of *A. configuratus* survived for ten days

TABLE II

Duration of nymphal life and survival of Canadian and Pakistani strains of *A. domesticus* at various temperatures

Temp. (°C.)	Strain	Initial No. of Hoppers	No. of Adults Obtained		% Survival	Duration of Nymphal Life (days)			
			Male	Female		Mean			Range
						Male	Female	Total	
23	C	60	12	13	42	104.0	114.0	109.0	78–148
	P	60	19	23	70	83.0	79.0	81.0	73– 98
28	C	80	35	30	81	55.8	52.9	54.5	45– 62
	P	146	45	58	71	46.0	44.8	45.3	38– 54
33	C	60	24	29	88	38.2	35.7	36.8	30– 46
	P	30	13	9	73	33.4	31.8	32.7	31– 35
35	C	110	37	53	82	35.3	33.7	34.4	29– 40
	P	140	43	60	74	26.9	26.2	26.5	23– 33
38	C	60	2	4	10	32.5	33.8	33.3	29– 44
	P	60	4	12	27	32.5	35.4	34.6	27– 44
41	C	90	2	7	10	35.5	37.5	37.2	32– 44
	P	30	1	4	17	34.0	36.3	35.8	31– 41

TABLE III

Duration of nymphal life and survival of *G. sigillatus* at various temperatures

Temp. (°C.)	Initial No. of Hoppers	No. of Adults Obtained		Survival	Duration of Nymphal Life (days)			
		Male	Female		Mean			Range
					Male	Female	Total	
23	30	7	6	43	118	102	110	75–155
28	60	16	28	73	51	53	52	47– 64
33	60	22	30	87	39	36	37	31– 50
35	90	29	42	79	33	31	32	27– 40
38	30	9	6	50	31	32	31	28– 33
41	30	9	8	57	37	33	35	33– 39

TABLE IV

Duration of nymphal life and survival of *A. configuratus* at various temperatures

Temp. (°C.)	Initial No. of Hoppers	No. of Adults Obtained		% Survival	Duration of Nymphal Life (days)			
					Mean			
		Male	Female		Male	Female	Total	Range
23	60	25	20	75	94	104	98	61–140
28	120	45	53	82	66	64	65	55– 79
33	90	38	32	78	50	51	51	43– 66
35	90	31	34	72	51	54	53	39– 73
38	50	–	–	0	–	–	–	–
41	60	–	–	0	–	–	–	–

and none for more than 50 days at 38°C., and 100% mortality occurred within ten days at 41°C.

Discussion

Kemper (1937) found that females of *A. domesticus* laid from 40 to 170 eggs. Stone (1953) obtained a maximum of 2600 offspring from a single female over a nearly ninety-day adult stage. This maximum is over twice as great as the maximum we observed. However, since our chief concern was to discover how many eggs a female would lay under our conditions and methods of handling, and when she would lay them, and not primarily to obtain the largest possible number of eggs, it is quite possible that this discrepancy is due to the difference in methods, especially that of egg collection.

Cappe de Baillon (1920) found that the nymph of the house cricket required 52 days for development at 28 to 35°C. Kemper (1937) estimated the nymphal developmental period to be 30 to 33 weeks at room temperature. Stone (1953) found that nymphs fed a high protein diet required 30 to 35 days to mature at 90°F. (32°C.), and that at 80°F. (27°C.) the length of the nymphal stage was greatly increased. Busvine (1955), feeding the crickets a complex dry diet supplemented with fresh greenstuff, found the following *minimal* periods for nymphal development:

Temp. (°C.)	Male	Female
40	40	41
35	35	35
30	50	?
26	108	115
23	165,174	222,238

These results are more or less comparable to our results, except for the much longer developmental time at 26 and 23°C. found by Busvine. One would scarcely expect close agreement in view of the variety of foods and rearing conditions employed, and the possibility of racial differences.

Perhaps the most interesting of these results is the great difference between the Canadian and Pakistani strains of *A. domesticus*. Although they have a similar range of temperatures which will permit survival (38°C. being lethal

TABLE V

Number and duration of nymphal stadia of *A. domesticus* (*Can.*) as determined by single rearing

Stadium	Duration of Stadium (days)							
	28°C.					35°C.		
I	4	5	4	6	6	3	3	5
II	4	10	5	9	8	5	3	3
III	5	8	8	9	8	11	3	2
IV	8	6	8	12	9	4	3	3
V	6	6	9	13	11	4	4	3
VI	6*	5	8	14	8*	5	3	5
VII	8	6*	9*	12*	13	4*	6	4
VIII		8	8	9		5	5*	5*
IX							5	5
	41 (M)	52 (M)	59 (M)	84 (F)	63 (M)	33 (F)	35 (F)	34 (M)

*Wing pads first appeared in this stadium.

to both), and respond in a similar way to temperature, the Pakistani strain develops much more rapidly than the Canadian at all temperatures. The Canadian adults are, however, on the average, larger and heavier. From Table VI it is apparent that while there is little or no difference at 35°C. in the minimal duration of the nymphal stadia, the minimal number of stadia in the Canadian strain is nine as against seven in the Pakistani, the stadia dispensed with by the latter occurring before the appearance of the wing pads.

A sex difference in the minimal periods of development of the house cricket at 40, 26 and 23°C. was reported by Busvine (1955) but in each case the female required the longer time to develop. In all cases in this work where there was a sex difference in the rate of development (except that of *A. configuratus* at 23°C.) the female always developed faster. The various strains and species showed considerable variation in this respect.

The mortality of males and females was not separately determined (although Qadri (1940) reports that it is possible to distinguish the sexes as early as the second instar), and this would, of course, affect the validity of the above observations. For temperatures in the optimal range, however, where the percentage survival was high, this consideration was probably of no importance.

In single rearing of the Canadian strain of *A. domesticus* (Table V) the number of moults were 7 to 8 at 28°C. and from 8 to 9 at 35°C. The interval between the moults varied from 6 to 14 days at 28°C. and from 3 to 6 days at 35°C. Both results differ from those of Cappe de Baillon (1920) who found eleven stadia, and Kemper (1937) who found ten to twelve.

The wing pads always appeared in the penultimate nymphal stadium in all species. The last two stadia were of longer duration than the others.

TABLE VI

Minimal duration of nymphal stadia as determined by group rearing at 35°C.

Stadium	Minimal Duration of Stadium (days)			
	A. domesticus (*Can.*)	*A. domesticus* (*Pak.*)	*A. configuratus*	*G. sigillatus*
I	3–4	3	6	4–5
II	4	3	4	3
III	3	4	3	4
IV	3	3	4	3
V	3	3	4	4
VI	3	4*	4	3–4
VII	4	4–5	4	4*
VIII	5*		4	4–8
IX	6		4*	
X			9	

*Wing pads first appeared in this stadium.

In group rearing a record of the sexes was not kept, but it may be supposed that those developing in the minimal time were largely females.

The fact that *A. domesticus* (*Can.*) passed through a greater number of instars at 35°C. than at 28°C. (Table VI) is not unusual, having been reported for a number of other insect species (Wigglesworth, 1950).

References

Blatchley, W. S. 1920. Orthoptera of Northeastern America. Nature Publ. Co., Indianapolis, Ind.

Browning, T. O. 1952. The influence of temperature on the rate of development of insects, with special reference to *Gryllulus commodus* Walker. *Austral. J. Sci. Res.*, B 5: 96-111.

Busvine, J. R. 1955. Simple methods for rearing the cricket (*Gryllulus domesticus* L.) with some observations on the speed of development at different temperatures. *Proc. R. Ent. Soc. Lond.* 30: 15-18.

Cappe de Baillon, P. 1920. Contributions anatomiques et physiologiques à l'étude de la reproduction chez les Locustiens et les Grilloniens. *La Cellule* 32: 1-193.

Chopard, L. 1936. Key to the Gryllidae of Ceylon. *Ceylon Jour. Sci.* Sect. B 20: 23.

Ghouri, A. S. K. and J. E. McFarlane. 1958a. Reproductive isolation in the house cricket. *Psyche* 64: 30-36.

Ghouri, A. S. K. and J. E. McFarlane. 1958b. Manuscript in preparation

Kemper, H. 1937. Beobachtungen über die Biologie der Hausgrille (*Gryllus domesticus* L.). *Z. Hyg. Zool. Schädl Bekampf* 29: 69-86. Abstract in *Rev. Appl. Ent.* (A) 26: 37, 1938.

O'Brien, F. E. M. 1948. The control of humidity by saturated salt solutions. *J. Sci. Instrum.* 25: 73-76.

Qadri, M. A. H. 1940. On the development of the genitalia and their ducts of Orthopteroid insects. *Trans. R. Ent. Soc. Lond.*, 90: 121-75.

Stone, P. C. 1953. The house cricket as a laboratory insect. *Turtox News* 31: 150-151.

Wigglesworth, V. B. 1950. The principles of insect physiology. Methuen, London.

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The External Morphology of the Immature Stages of the Beech Leaf Tier, *Psilocorsis faginella* (Chamb) (Lepidoptera: Oecophoridae), with Notes on Its Biology in Nova Scotia[1]

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Introduction

The beech leaf tier, *Psilocorsis faginella* (Chamb.) is common on American beech, *Fagus grandifolia* Ehrh., in stands of northern hardwoods throughout Nova Scotia. During the feeding stage, the insect is conspicuous because of its leaf-tying habit (Fig. 1).

The literature on *P. faginella* is mostly taxonomic. Forbes (1923) and Craighead (1950) mentioned the leaf-tying habit of the larva and the colour of the ultimate instar. Chambers (1872) originally described the adult as *Hagno faginella*, then placed it in the genus *Cryptolechia* (1878). The genus was later changed to *Psilocorsis* (Busck, 1908). Clark (1941) described the adult in more detail and listed *Psilocorsis ferruginosa* (Zeller) as a synonym.

Field work was done in a stand of northern hardwoods at East Folly Mountain, Colchester County, during 1952 and 1953.

Morphology

The nomenclature of parts used in this paper is based on works by Duport (1946), sclerites of the face; Crumb (1929) and Derthier (1937), maxilla and labium; and Peterson (1948), other parts. The systems of Heinrich (1916) and Fracker (1915) were used in naming the setae of the head and body, respectively. Drawings were proportioned by measurements of parts or were made with the aid of a gridded microscope-eyepiece.

EGG

Egg 0.5 mm. long, 0.3 mm. wide (average for 12 eggs), pale green, translucent, somewhat flattened on underside; chorion soft and striated, striae composed of rows of minute square pits.

LARVA

First Instar.—Head 0.20 mm. wide (Table I), honey-coloured except for a black area in each ocellar region; mandibles dark brown with five distinct teeth (Fig. 11). Prothoracic shield absent (Fig. 19). Body about 1.5 mm. long, pale green; pinacula indistinct; ventral prolegs on abdominal segments 3-6, one pair of anal prolegs.

Second Instar.—Head 0.32 mm. wide (Table I), brownish black; mandibles with three distinct teeth, upper part of cutting edge crenulate (Fig. 12), prothoracic shield entire, brownish black; prespiracular plate irregularly indented (Fig. 20). Body about 2.5 mm. long, pale green; pinacula indistinct.

Third Instar.—Head 0.53 mm. wide (Table I), brownish black; mandibles similar to those of second instar, but with slightly less distinct teeth (Fig. 13). Prothoracic shield similar to that of second instar, but prespiracular plate more elongate (Fig. 21). Body about 5.0 mm. long, pale green; pinacula indistinct.

Fourth Instar.—Head 0.89 mm. wide (Table I), brownish black, mandibles with three indistinct teeth, remainder of cutting edge straight (Fig. 14). Prothoracic shield divided at meson (Fig. 22), brownish black. Body about 10.0 mm. long, pale green; pinacula brownish black, conspicuous.

Fifth Instar.—Head 1.54 mm. wide (Table I), reddish brown; mandibles with one indistinct tooth, remainder of cutting edge straight (Fig. 15). Prothoracic

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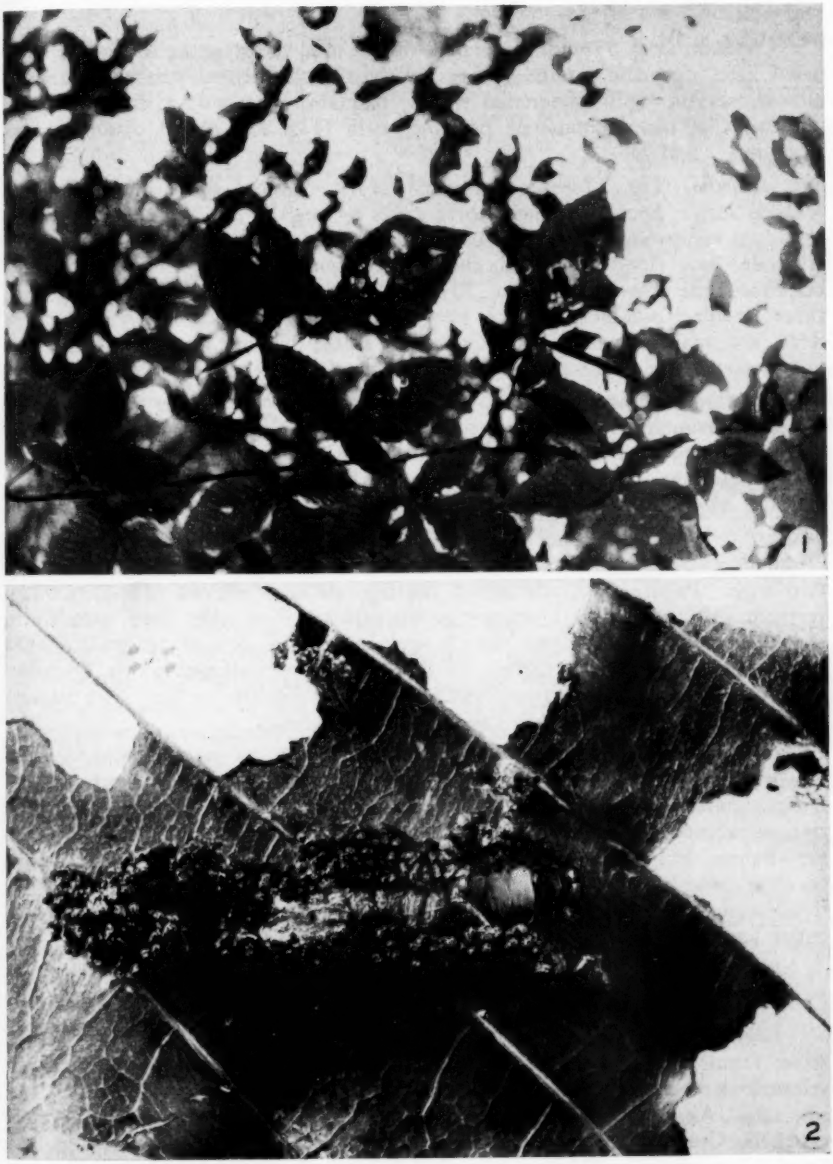


(Figs. 1-2). 1. Typical appearance of beech foliage infested with *Psilocorsis faginella* (Chamb.). 2. Larva of *Psilocorsis faginella* (Chamb.) feeding on beech leaf.

shield divided at meson (Fig. 23), reddish brown. Body about 13.0 mm. long, pale green, turning pink just prior to entering prepupal phase; pinacula brown, conspicuous.

Cranium, (Fig. 3) with midcranial sulcus, mcs, transfrontal, tfs, and frontal-genal sulci, fgs, and frontal sutures, fs, distinct. Coronal sutures, cs, short, almost merging with midcranial sulcus; frontal-clypeal sulcus, fcs, indistinct; clypeus, Clp, membranous; six pairs of ocelli (Fig. 25). Setal pattern shown in figures 3 and 25.

Antenna, (Fig. 5) three-segmented. First segment short, three times as wide as long. Second segment three times as long as first segment, bears one sensillum campaniformium, SC, basally, and five sensilla apically; two sensilla trichodea, one (long hair), LH, about three times length of antennal segments combined, the other (short hair), SH, equal in length to first antennal segment; three sensilla basiconica, SB, one very small, and two, each nearly as long as third antennal segment. Third segment small, bearing one sensillum basiconicum, SB, and one sensillum styloconicum, SS.

Labrum, outer surface (Fig. 7) light brown, glabrous; four pairs of setae; apical notch moderately emarginate. Ephipharynx (Fig. 8) covered with small spines; three pairs of setae.

Maxilla, (Figs. 6 and 10) with cardo, Cd, weakly delineated, mostly membranous, bearing a hook-like sclerite basally. Stipes, S, mostly membranous, bearing two sclerites: one sclerite roughly T-shaped with part obscured by submentum, Smt; other sclerite, on outer edge of stipes, semicircular, bearing two setae. Palpifer, Plf, sclerotized, bearing one seta. Palpus (Fig. 10) three-segmented; first segment bearing a maxillary lobe, four setae (two spatulate in shape) at base of lobe, two sensilla styloconica, SS, and three small sensilla basiconica, SB, on upper surface of lobe; second segment cylindrical, smaller than maxillary lobe; third segment cylindrical slightly smaller than second segment, bearing seven sensilla basiconica, SB, apically.

Labium, (Figs. 6 and 9) with submentum (Fig. 6) membranous, pointed basally, two conspicuous setae at its center. Mentum, Mt, sclerotized, two inconspicuous setae near apical margin. Palpiger (Fig. 9, Plg) consisting of two semicircular sclerites surrounding bases of labial palpi, Plp, and spinneret, Sr. Palpus, Plp, three-segmented; first segment as long as second and third combined and bearing a subapical papilla, P; third segment hair-like. Spinneret, thin, longer than labial palpus; strengthened by three sclerotic bars running its entire length, outer two forming a collar that partly surrounds its base.

Hypopharynx, (Fig. 4) lightly sclerotized, covered with small spines.

Setal Pattern, shown in figures 24 and 26; pinacula lightly sclerotized.

Legs: Prothoracic leg (Fig. 16) with membranous coxa, Cx, bearing four setae; femur, Fm, partially sclerotized, bearing two setae; tibia, Tb, partially sclerotized, bearing four setae; tarsus, Tar, sclerotized, bearing one claw and one seta. Abdominal proleg (Fig. 17) bearing three setae mesally; biordinal crochets, Cro, 32-52 in number, arranged in a circle. Anal proleg (Fig. 18) bearing six setae basally, ten setae apically; biordinal crochets, Cro, 32-36 in number, arranged in a semi-circle.

PUPA

Pupa about 8 mm. long, reddish brown (Figs. 30 and 31). Setal pattern of segments 3 and 4 (Fig. 32) with seta σ missing on segment 3 and setal puncture between setae ρ and κ on segments 3 and 4, otherwise similar to setal pattern

TABLE I

Head Width Measurements of Five Larval Instars of *Psilocorsis faginella* (Chamb.)

Instar	No. measured	Range (mm.)	Mean (mm.)	Calculated width* (mm.)
I	86	.20– .23	.20	.17
II	178	.29– .39	.32	.30
III	171	.42– .59	.53	.52
IV	515	.62–1.30	.89	.89
V	321	1.34–1.73	1.54	1.54

*By "Dyar's law", using a ratio of 0.58 between instars IV and V.

of larva (Fig. 24); setal pattern of segments 8 and 9 with one ventral seta σ absent on segment 8 of female (Fig. 28), two setae σ absent on segment 9 of male and female (Figs. 27, 28 and 29) otherwise setal pattern similar to that of larva (Fig. 26). Abdominal spiracles on segments 2-8 (Sp, Fig. 31). Proleg scars present on segments 4-6 (Figs. 30 and 32). Anal opening, An, a longitudinal slit on flattened portion of segment 10 near caudal margin (Figs. 28 and 29). Male genital opening, a short slit (GO, Fig. 29); female genital openings (GO, Fig. 28) two confluent slits, between two elevated lobes, and apparently on segment 8.

Life History and Habits

Eggs were obtained by placing adults in cages with potted beech trees. Most of the information on larval development was obtained from collections of larvae taken at one or two day intervals throughout the season. The number of instars was determined from head capsule measurements of 1,271 larvae preserved in 70 per cent alcohol.

In 1953, adults were observed in flight during the period July 21 to August 1. Mating was observed only at night. The sex factor (number of females/number of individuals), based on 144 individuals reared from pupae, was 0.51.

Eggs were deposited singly, usually on the underside of the leaf in the small recesses formed by the junction of the main and the lateral veins, or occasionally beside veins in other areas of the leaf. No more than six eggs were found on any leaf. Eggs hatched in about two weeks.

Head capsule measurements indicated that there are five instars (Table I). Ranges of head capsule widths did not overlap and the theoretical widths by "Dyar's law" were close to observed widths.

The newly-emerged larvae skeletonized leaf areas next to the veins and later spun silken tubes (Fig. 2) which tied the leaves together. Up to nine larvae, representing the first, second and third instars, fed between tied leaves. Fourth and fifth instar larvae usually fed singly. Many fifth instar larvae migrated to fresh leaves toward the end of their developmental period. There was considerable overlapping in the occurrence of the five instars.

Immediately prior to the prepupal phase (in late September), the larvae turned from pale green to pink and dropped to the ground where they pupated and over-wintered beneath leaves.

Parasites

The following species of parasites were reared from *P. faginella*:

DIPTERA

Tachinidae:

Lophosiocera sp.
Psalidopteryx psilocorsiphaga Brks.
Zenillia (*Eusisyropa*) *blanda* (O.S.)

HYMENOPTERA

Braconidae:

Macrocentrus impressus Mues.

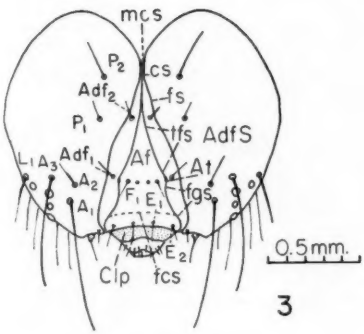
Ichneumonidae:

Horogenes aestivalis (Vier.)
Horogenes sp.
Labrorychus sp. (apparently undescribed)
Phaeogenes sp.
Phobocampe sp.
Phytodietus sp.
Pimpla aquilonia Cress.

(Figs. 3-32). 3. Head, anterior view. 4. Hypopharynx, spinneret and palpi, anterior view. 5. Right antenna, anterior view. 6. Maxillolabial-hypopharyngeal complex, posterior view. 7. Labrum, anterior view. 8. Labrum, epipharyngeal surface. 9. Apex of labium, posterior view. 10. Right maxillary palpus, posterior view. 11-15. Right mandibles of instars 1-5 respectively, inner view. 16. Right mesothoracic leg, inner view. 17. Right abdominal proleg, ventral view. 18. Right anal proleg, ventral view. 19. Setal map of prothorax, instar 1. 20-23. Prothoracic shields of instars 2-5 respectively. 24. Setal maps of thoracic segments 1 and 2, abdominal segments 1, 3 and 7 (larva). 25. Arrangement of genal setae and ocelli, right side. 26. Setal maps of abdominal segments 8-9 (larva). 27. Basal portion of pupa, dorsal view. 28. Basal portion of female pupa, ventral view. 29. Basal portion of male pupa, ventral view. 30. Pupa, ventral view. 31. Pupa, dorsal view. 32. Setal maps of abdominal segments 3, 4, 7 and 8 (male pupa).

Abbreviations Used in Figures

A1-10, abdominal segments 1-10
Aca, antacoria
AdfS, adfrontal sclerite
Af, antefrons
An, anus
Ant, antenna
At, anterior tentorial invagination
Cd, cardo
Clp, clypeus
Cre, cremaster
CreH, cremastral hook
Cro, crochets
cs, coronal suture
Cx, coxa
E, eye
fcs, fronto-clypeal sulcus
fgs, fronto-genal sulcus
Fm, femur
FmTh1, femur, 1st thoracic leg
FmTh2, femur, 2nd thoracic leg
FmTh3, femur, 3rd thoracic leg
Fr, frons
fs, frontal suture
GO, genital opening
Hphy, hypopharynx
LH, long hair (sensillum trichodeum)
LTh3, 3rd thoracic leg
P, papilla
Plf, palpifer
Plg, palpiger
Plp, palpus
PrLS, proleg scar
mcs, midcranial sulcus
Md, mandible
Mt, mentum
Mx, maxilla
MxPlp, maxillary palpus
S, stipes
SB, sensillum basiconicum
SC, sensillum campaniformium
SH, short hair (sensillum trichodeum)
Smt, submentum
Sp, spiracle
Sp2, spiracle, 2nd thoracic segment
Sr, spinneret
SS, sensillum styloconicum
Tar, tarsus
Tb, tibia
tfs, transfrontal suture
Th1, 1st thoracic segment
Th2, 2nd thoracic segment
Th3, 3rd thoracic segment
V, vertex



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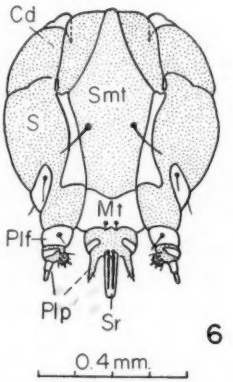

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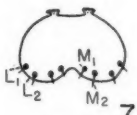

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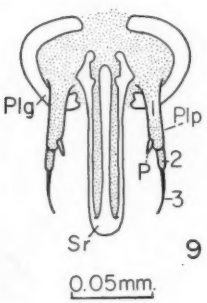

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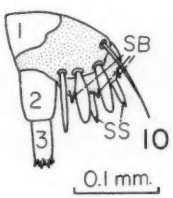

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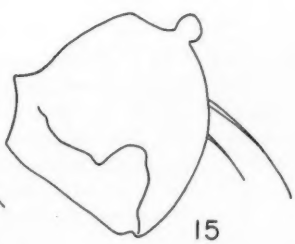

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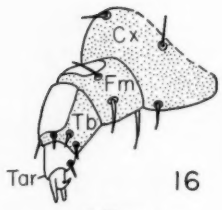
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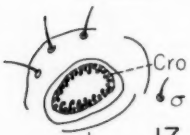
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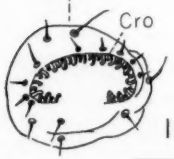
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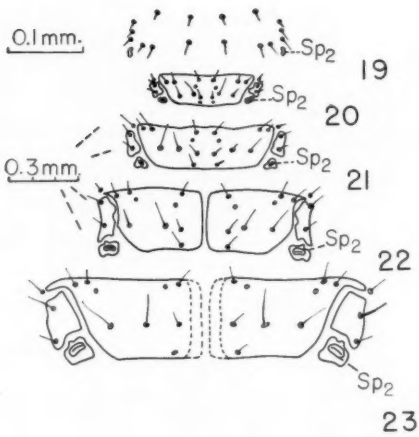
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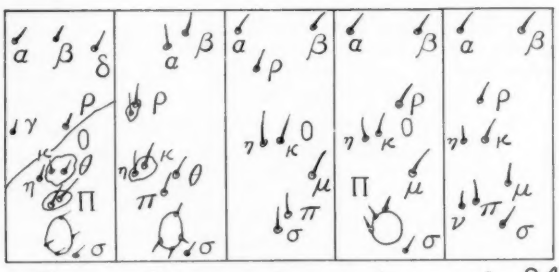
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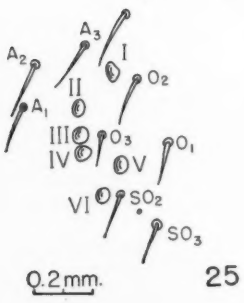
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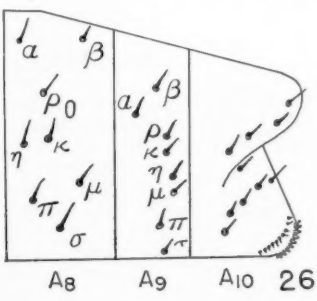
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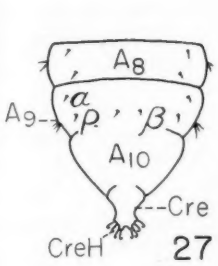

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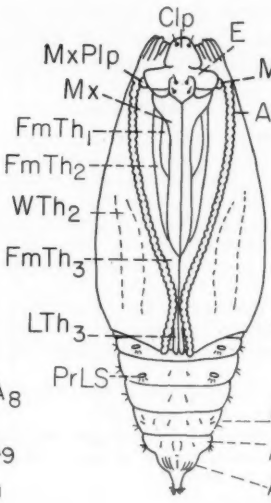

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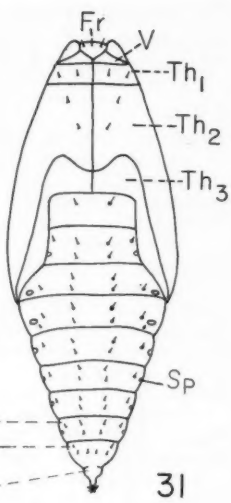

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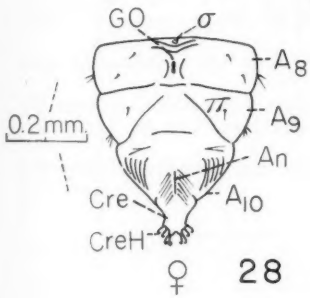

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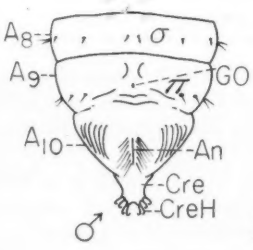

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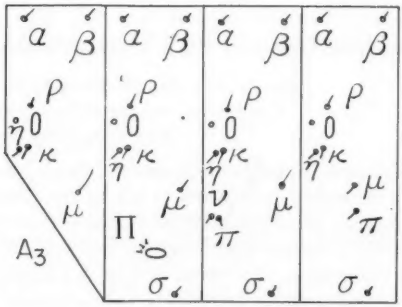

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Summary

Psilocorsis faginella (Chamb.) is a common defoliator of *Fagus grandifolia* Ehrh. in Nova Scotia. All stages, except the adult, are described. Adults appear in late July and deposit eggs, usually on the underside of beech foliage. The eggs hatch in about two weeks. The larvae complete their development in five instars and by late September drop to the ground and pupate in the litter. Several species of parasites of the families Tachinidae, Braconidae and Ichneumonidae were obtained from rearings of *P. faginella* larvae.

Acknowledgments

I wish to express my sincere appreciation to Dr. Alvah Peterson, Dept. of Zoology and Entomology, Ohio State University, who kindly criticized the manuscript and offered many helpful and valuable suggestions. I wish also to express my thanks to officers of the Forest Biology Laboratories at Debert and

Fredericton for their comments and suggestions, and to Dr. W. R. M. Mason and Messrs. G. S. Walley and G. E. Shewell, of the Systematic Unit, Entomology Division, Canada Agriculture, who identified the parasite material.

References

Busck, A. 1908. A generic revision of American moths of the family Oecophoridae with descriptions of new species. *Proc. U.S. Nat. Mus.* 35: 187-207.

Chambers, V. T. 1872. Microlepidoptera. *Can. Ent.* 4: 131-132.

Chambers, V. T. 1878. *U.S. Geol. Surv. Terr. Bull.* 4: 84-120, 137.

Clark, J. F. G. 1941. Revision of the North American moths of the family Oecophoridae with descriptions of new genera and species. *Proc. U.S. Nat. Mus.* 90: 33-286.

Craighead, F. C. 1950. Insect enemies of eastern forests. *U.S. Dept. Agr. Misc. Pub.* 657: 461.

Crumb, S. E. 1929. Tobacco cutworms. *U.S. Dept. Agr. Tech. Bull.* 88.

Derthier, V. G. 1937. Gustation and olfaction in Lepidopterous larvae. *Biol. Bull.* 72: 7-23.

Duport, E. M. 1946. Observations on the morphology of the face in insects. *J. Morph.* 79: 371-418.

Forbes, W. T. M. 1923. The Lepidoptera of New York State and neighbouring states. *Cornell Univ. Agr. Expt. Sta. Mem.* 68: 236.

Fracker, S. B. 1915. The classification of Lepidopterous larvae. *Illinois Biol. Monogr.* 2.

Heinrich, C. 1916. On the taxonomic value of some larval characters in the Lepidoptera. *Proc. Ent. Soc. Washington* 18: 154-164.

Peterson, A. 1948. Larvae of insects, Part 1, Lepidoptera and plant infesting Hymenoptera. *Ohio State University, Columbus, Ohio.*

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A Rearing Cabinet with Temperature and Humidity Controls[1]

By A. W. MacPhee and B. H. Patterson[2]

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A series of rearing chambers that have given satisfactory control of temperature and humidity have been in use in the entomological laboratory at Kentville during the past three years. The unit requires very little attention except a service check of the cabinets every two or three months.

The dimensions are given in Fig. 1 except for the depth, which is 30 inches on the outside. The cabinet is constructed of ¾-inch plywood without a supporting frame. Trays with perforated steel bottoms are arranged inside the cabinet on adjustable shelf brackets. The cabinet is provided with an upper and a lower door with removable jamb between them that may be removed when installing the trays in the cabinet. The doors are provided with a double glass window, which in turn is covered by a plywood door. A thermostat and a hygrostat are installed on the inside wall of the chamber about one foot from the bottom. The cabinet sets on a 15-inch base as shown in Fig. 1. The cabinet is painted inside with a steam-resistant paint to facilitate cleaning, and is provided with two 15-watt fluorescent lights inside at the top.

The temperature conditioning of the cabinet occurs as follows: a blower fan (Fig. 1, C) which runs continuously, removes air from the top of the cabinet and forces it down through the air duct past a heater (G) and into the cabinet at the bottom. A thermostat mounted inside the cabinet acts as a switch on the 110-volt power supply to the heaters. Two 165-watt elements are controlled by a three-way switch (A), allowing a choice of 82.5, 165, or 330 watts at point G.

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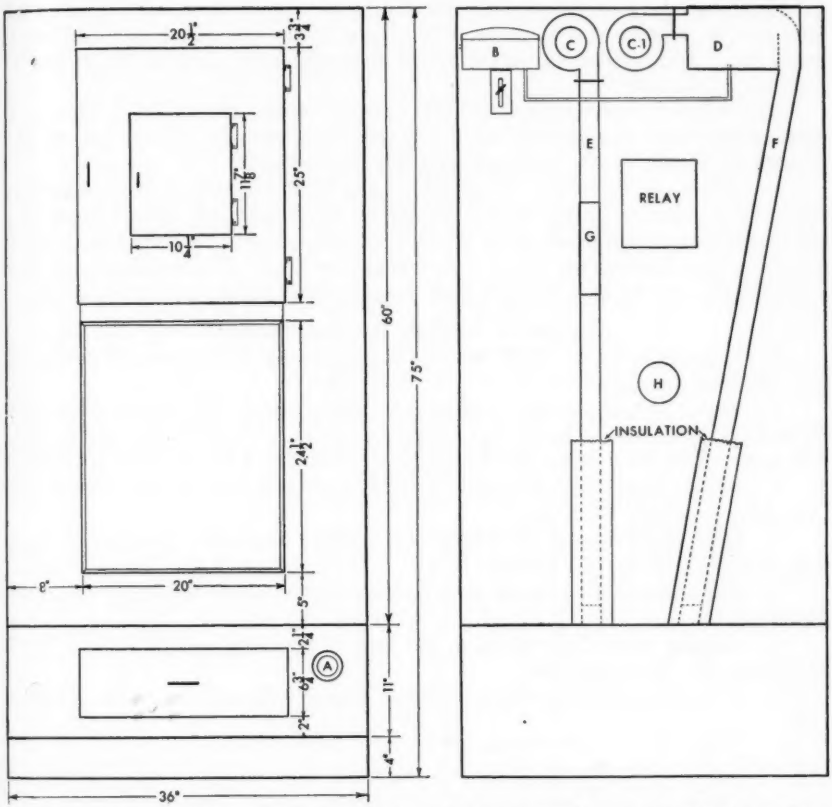

Fig. 1. Plans of cabinet. Left, front view, with lower door removed. Right, rear view, without wiring. A, heater switch; B, water control; C, blower fans; D, humidifier; E & F, air ducts; G, heater; H, junction box.

The humidity conditioning of the cabinet is provided for as follows: when moisture is required the hair hygrostat closes, activating a relay that starts the fan motor (C-1) blowing air over the moisture-soaked glass wicks in the humidifier (D) down through the air duct (F) and into the cabinet below the lower shelf. When the moisture requirements are met the blower fan switches off. The water level in the humidifier is maintained by a float control (B), fed by the main water supply.

The air ducts, fans, and doors of the cabinet must be nearly airtight to avoid undue loss of conditioned air. This is particularly true when a high humidity is required.

The temperature control of the cabinet is satisfactory for rearing purposes, not varying over one degree Fahrenheit from the thermostat setting under steady conditions. The humidity control varies from about a three per cent differential at fine adjustment of the hygrostat to six or seven per cent at coarse adjustment. The maximum relative humidity obtainable with the humidifier is about 85 per cent. The minimum humidity is dependent on the outdoor temperature and humidity, being determined by the amount of moisture in the outdoor air.

The rearing room housing the incubators is held to about 60°F., or to the outdoor temperature if it is above 60°F., by a thermostatically controlled ventilation fan. The cabinets can therefore be operated from about 65°F., to 100°F. for most of the year.

The cabinets were designed to meet the needs of the officers of this laboratory who made many suggestions regarding the construction. The cost of the cabinets excluding labour was approximately $250.00 each.

In addition to the above described cabinet there are two cooled cabinets in use. These insulated cabinets are cooled by a refrigerated brine system that allows their operation down to 45°F. These cabinets are humidified by a steam generator that feeds steam into the air circulation duct. The cooling coils have a dehumidifying effect, allowing a wide range of humidity control in the cabinets.

Equipment Used in Rearing Cabinet

1. Humidifier wicks:—Five No. 490 Vapoglas humidifier plates, Wait Skuttle Co., Oakville, Ontario.
2. Motor blower assembly:—Humidifier fan assembly: Model 197-43-05-05B, RPM 2775, 0.6 amps. Heater fan assembly: Model 186-43-05-10B, RPM 1550, 0.35 amp. Both from Dominion Electrohome Industries Ltd., Kitchener, Ontario.
3. Relay:—Aminco supersensitive relay 4-5300, American Instrument Co., Inc., Silver Springs, Maryland.
4. Hair hygrostat:—Type H6A1X3 humidity controller, Honeywell Controls Ltd., 133 Young St., Halifax, N.S.
5. Thermostat:—Fenwal all-purpose type 17500, Fisher Scientific Co., Ltd., Montreal, Que.
6. Heating unit:—No. 95115-A, 115-volt, Central Scientific Co., Ltd., 7275 St. Urbain St., Montreal, Que.
7. Humidifier float control:—Canadian General Electric Co., Ltd., Halifax, N.S.

(Received August 1, 1957)

Timing Soil-surface Applications of Chlordane Dust Against the Onion Maggot, *Hylemya antiqua* (Meig.) (Anthomyiidae: Diptera), in Onion Seedlings[1]

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Several Canadian workers have reported various results in the control of the onion maggot, *Hylemya antiqua* (Meig.), with chemicals applied to the soil surface (Dustan, 1938; Matthewman *et al.*, 1942; McLeod, 1946; Perron *et al.*, 1953; Finlayson and Handford, 1954). In these tests, the date of the first application of insecticide coincided with early oviposition of the insect, the second and third applications following at weekly or ten-day intervals. Satisfactory control was therefore dependent to a great extent on the grower's ability to recognize the beginning of oviposition by the pest in the field. However, many growers find this recognition difficult and poor control often results from the three-application program.

In southern Quebec, the majority of growers produce onions for the fall and winter market and seeding usually takes place during the first two weeks of May. The first eggs are found in the field about May 19 in early seasons, May 25 in

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TABLE I

Onion maggot control obtained with 5 per cent chlordane dust applied on three dates in sandy loam soil, St. Césaire, Que. 1951–1954

Dates of application			1951			1952			1953			1954			Mean	
May 25	June 1	June 8	Plants		Control	Plants		Control	Plants		Control	Plants		Control	Control	Angular transformation*
			Killed	Total	%	Killed	Total	%	Killed	Total	%	Killed	Total	%	%	
x	x		34	2859	94.6	16	3657	95.6	28	2651	96.0	13	1229	92.9	95.3	5.6
x	x	x	60	3024	91.4	9	3534	97.5	12	2182	97.9	25	1126	84.9	94.2	5.9
x		x	187	3001	72.1	43	3609	88.1	75	2403	88.2	27	1318	86.2	82.5	9.6
	x	x	278	3272	61.7	26	3559	93.1	26	2257	95.6	34	1062	78.3	80.4	9.8
	x		283	2987	57.2	55	3654	85.1	34	2504	94.9	39	1161	77.3	78.2	10.6
x			199	2699	66.7	97	3339	71.3	111	2263	81.3	37	1313	80.9	74.9	12.0
		x	426	3068	37.4	307	3416	11.9	348	2420	45.3	37	1022	75.4	38.7	18.1
Check			619	2788	–	319	3144	–	622	2366	–	141	955	–	–	25.0

x–Difference nescesary for significance at 1% level, 6.2; at 5% level, 4.6.

normal seasons, and June 1 in late seasons. It appeared that if the three applications against *H. antiqua* were made about a week later than these three dates, satisfactory control of this pest might be obtained for any given year, so that the growers might make the applications on fixed dates. To test this possibility and also to determine whether all three applications were necessary, an experiment with chlordane dust as soil surface applications was conducted at St. Césaire, Que., from 1951 to 1954. Previous tests (Perron *et al.* 1953) had shown chlordane to be one of the most effective materials against the onion maggot in this province as a soil-surface treatment.

Materials and Methods

The variety Yellow Globe Danvers was sown during the first week of May in sandy loam soil in four-row plots, the rows being 20 feet long and 17 inches apart. There were four replicates, each having eight plots. The numbers and dates of applications tested are shown in Table I. The insecticide was applied to the two centre rows of each plot at 0.5 to 0.75 pounds per 160 feet of row. To obtain thorough coverage of the dust around the bases of the plants, the insecticide was shaken through a small cheesecloth bag. Dead plants were removed and counted thrice weekly during June and early July and an analysis of variance on angular transformation of percentages of plants killed was made.

Results and Conclusions

Table I shows that two applications made on May 25 and June 1 were as effective as three, and that the one on June 1 gave commercial control and was more effective than a single application on another date. In a normal year hatching and establishment of the larvae reach their peaks between May 25 and June 10. Hence, in applications at these times the chlordane dust, which has a satisfactory residual effect for several days under normal weather conditions (Brown 1951), protected the onion seedlings at the time of maximum egg-laying and hatching.

Summary

In experiments in sandy loam soil at St. Césaire, Que., from 1951 to 1954, 95 per cent control of the onion maggot, *Hylemya antiqua* (Meig.) in onion seedlings, was obtained with applications of five per cent chlordane dust on May 25 and June 1. A third application on June 8 did not improve the protection. A single application on June 1 gave commercial control and was more satisfactory than a single application on either of the other dates.

Acknowledgment

The authors acknowledge the assistance of Dr. J. J. Cartier and Mr. R. Crête of the St. Jean laboratory in the statistical analysis of the results, and of Dr. E. J. LeRoux in the preparation of the manuscript.

References

Brown, A. W. A. 1951. Insect Control by Chemicals. John Wiley and Sons Inc., New York.

Dustan, A. G. 1938. Some results in controlling the onion maggot with calomel. *68th Ann. Rept. Ent. Soc. Ontario* (1937), pp. 37-43.

Finlayson, D. G., and R. H. Handford. 1954. Experiments on control of the onion maggot, *Hylemya antiqua* (Meig.), in the interior of British Columbia. *Canadian J. Agr. Sci.* 34: 385-388.

Matthewman, W. G., A. G. Dustan, and A. C. Davis. 1942. A timing experiment with combinations of mercury insecticides used for the control of the onion maggot. *72nd Ann. Rept. Ent. Soc. Ontario* (1941), pp. 21-23.

McLeod, W. S. 1946. Hexachlorocycohexane in the control of the onion maggot. *J. Econ. Ent.* 39: 631-637.

Perron, J. P., J. Lafrance, and M. Hudon. 1953. Control of the onion maggot with insecticides. *34th Ann. Rept. Quebec Soc. Prot. Plants* (1952), pp. 37-40.

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Effect of Host Distribution on the Reproduction of *Encarsia formosa* Gahan (Hymenoptera: Chalcidoidea)[1]

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That insect parasites regulate and, in the case of newly introduced species, sometimes reduce the average density of insect pests has led to an examination of the properties of parasites in general. Consideration has been given to the manner in which parasites select hosts for oviposition and to the physiological and psychological basis of this selection. The distribution of parasite progeny among suitable hosts has been analysed in many cases, for the fewer the hosts that are superparasitized for any given number of parasite eggs laid the greater the efficiency of the parasite in reducing host density. It is obvious that before the factors of host selection and superparasitism become important in host-parasite interaction the parasite must find the host individuals. When the hosts are confined to a relatively small area the potential oviposition of the parasite, subject to discrimination among hosts and restraint in oviposition, often determines the level of parasitism. As distance between individuals of the host population becomes greater, however, it is necessary for the parasite to search the environment more extensively. Therefore, the ability of the parasite to find hosts is a factor of prime importance in determining its influence on the density of its host. The success with which a parasite discovers hosts in relation to host density is determined, of course, by several characteristics of the parasite species and by the modification of these characteristics through variations in the physical environment.

In discussion of the ability of insect parasites to find their hosts, host density is usually considered as the number of hosts per unit area or volume, i.e., as average host density. The nature of host distribution, however, has a considerable influence on the success of entomophagous insects. In considering the role of host distribution Smith (1939, p. 314) stated: "At a given *average* density, and providing the entomophagous insect originates within the area of heavy infestation, the actual distance which it must travel to find a succession of hosts is less where the individuals are closely grouped than where they are uniformly separated. For this reason, within certain limits the more the host dispersion tends toward the colonial type, the more effective an enemy of given powers of discovery is in maintaining its average density at a low value".

Differences in host distribution are cited by Smith (1939) as resulting in the success of the vedalia, *Rodolia cardinalis* (Muls.), as a predator of the cottony cushion scale and in the failure of another coccinelid, *Rhizobius ventralis* Erichs., as a predator of the black scale. Parsons and Ullyett (1936) found that *Trichogramma lutea* Grlt. was less effective as a parasite of *Heliothis zea* (Boddie) when the host eggs were deposited on cotton than on maize. They attributed this to "The growth habit of the cotton bush and the scattered manner of egg deposition thereon ----------".

Though it is not possible to reproduce differential host distribution in an area as large as that encountered in the field, the effects of the interrelations of host distribution and host or parasite density on the level of parasitism can be examined experimentally. An experimental procedure in which the parasite originates in and searches among concentrations of the host, as stipulated by Smith (1939), would be difficult to establish in the laboratory; but the influence

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of a colonial or highly contagious distribution, as observed by Parsons and Ullyett (1936), on the reproduction of an insect parasite can be analysed. Ullyett (1949a) found that there was no significant difference in parasitism when the host, the eggs of *Anagasta kühniella* (Zell.), was uniformly distributed and scattered at random over the experimental area and exposed to attack by the parasite *Chelonus texanus* Cress. The area of host distribution was little more than one square inch, however, and it is therefore unlikely that the searching ability of the parasite came into play or that there was much difference in the two distributions.

The greenhouse whitefly, *Trialeurodes vaporariorum* (Westw.), and its chalcid parasite *Encarsia formosa* Gahan are suitable for an investigation in the laboratory of problems that involve host distribution. The immature stages of the host, which are attacked by the parasite, are sedentary and can be removed from the host plant and spaced as desired in an experimental area. In nature the parasite, which is 1 mm. in length, searches for hosts on the underside of the leaf of the host plant, so that a flat surface large enough to ensure that the parasite must search for its hosts can be provided to simulate natural conditions. The level of parasitism can be regulated, not only by the numbers of hosts and parasites used but also by the period of search of the parasites.

This paper deals with the influence of host distribution on the relations of host and parasite densities to the reproduction of *Encarsia formosa*.

Materials and Methods

The greenhouse whitefly develops on the underside of the leaf of the host plant. Except the first larval instar, all the immature stages are sedentary. *Encarsia formosa* is an internal parasite of the larval instars of the greenhouse whitefly, the eggs being deposited by the adult female through the dorsal surface of the host.

Stocks of both host and parasite, from which the experimental individuals were drawn, were propagated on tomato plants in the greenhouse and were thus subject to some variation in environmental conditions. Parasite-free, early-fourth-instar larvae, about 1 mm. in length, were used as the host. All larvae used on each day's group of experiments were taken from the same leaflet of tomato immediately before exposure to the parasite females. Blackened scales (a parasitized host turns black about two weeks after oviposition by the parasite) of the host were incubated at 24°C. and 80 per cent relative humidity to obtain a supply of adult parasites, 24-28 hours old. The cage that formed the experimental universe was five by five inches in area and less than one inch in height. The bottom of the cage was a sheet of glass covered with moist, green blotting paper, which in turn was covered by a sheet of cellophane. Strips of plastic, containing ventilating holes, formed the sides of the cage, and the top was a sheet of glass.

The hosts were placed on the cellophane in three patterns as illustrated in Fig. 1, in which 36 scales are used as an example. In the equal distribution the dispersion of the hosts made the actual density approximately equal to the average density of *Trialeurodes* larvae whereas in the central and corner distributions the hosts covered an area of one square inch, i.e., four per cent of the total cage area. The cellophane allowed the host larvae to remain moist and suitable for oviposition while permitting the parasite females to wander freely over the area of host distribution.

Each experiment was begun by placing the required number of hosts in one of the three patterns of host distribution on the bottom of the cage and intro-

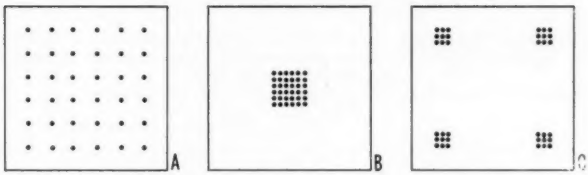

Fig. 1. The three distributions of 36 hosts on a 25-square-inch plane. A, equal distribution; B, centre distribution; C, corner distribution.

ducing the required number of female parasites. The glass top was then fastened into place, the cage was inverted so that the hosts were suspended from the cellophane, and the cage was incubated at 24°C. and 80 per cent relative humidity for 18 hours. The position of each host and the number of parasite eggs that it contained were then recorded. The three patterns of distribution were used each day to minimize any effect of variation in environmental conditions used during rearing of host and parasite. Each experiment was replicated 10 times.

Effects of Host Distribution and Host Density

The interaction of host distribution and host density was examined when 20 female parasites searched among five different numbers of hosts, i.e., 4, 16, 36, 64, and 100, distributed in equal, central, and corner patterns over a 25-square-inch area. The searching of the parasites was analysed with respect to the success in finding hosts, the oviposition of the parasite, and the distribution of parasite progeny among the hosts exposed.

Level of Parasitism

The relation of the number of hosts parasitized to the number of hosts exposed is recorded in Table I and shown in Fig. 2. With all three distributions there was an increase in the number of hosts attacked as the number of hosts exposed was increased. Although there were more hosts attacked, at each density, in the colonial than in the equal distribution, significant differences were obtained only at densities of 36, 64, and 100. The regressions of hosts parasitized on hosts exposed, shown in Fig. 2, indicated that a grouping of host larvae resulted in a higher parasitism than when the host was uniformly distributed; a comparison of the equal and central distributions indicated that the regressions coefficients were significantly different ($F=6.28$; d.f. 1, 6; $P<.05$) and the means were also significantly different $F=15.84$; d.f. 1, 6; $P<.01$). In addition Fig. 2 shows that slightly more hosts were attacked when they were split up into four isolated colonies than when they were aggregated into one colony but the two regressions were not significantly different. Although the observed parasitism was somewhat higher than that calculated on a basis of linear relationship (Fig. 2, central and corner distributions) at host densities of 36, and 64, the general trend, within each of the three patterns, was for the numbers of hosts attacked to increase with the numbers of hosts exposed as the percentages of hosts parasitized, given in Table I, were approximately equal.

The parasite tended to find hosts in proportion to the density of hosts exposed to attack. This would occur if a certain percentage of the hosts were not acceptable to the parasite. However, the colonial distributions resulted in a higher percentage of parasitism than did the equal one at each of the five host densities. The acceptability of the host scales to the parasites was further tested by reducing the area of search from 25 to four square inches for the 36 hosts distributed in the equal pattern. The results for the 25-square-inch area (Table

TABLE I

Reproduction of *Encarsia formosa* when 20 female parasites searched for various numbers of hosts distributed in three patterns on a 25-square-inch plane (means of ten replicates)

	Distribution	Numbers of hosts exposed				
		4	16	36	64	100
No. of hosts parasitized	Equal	2	10	20	38	54
	Central	3	11	26*	45	63*
	Corner		11	27*	46*	64*
No. of parasite eggs laid	Equal	3	15	38	64	80
	Central	5	23	57	92*	104*
	Corner		22	53	94*	114*
Percentage of hosts parasitized	Equal	53	61	56	60	54
	Central	83	68	71	70	63
	Corner		68	74	72	64
No. of eggs per host	Equal	.8	.9	1.1	1.0	.8
	Central	1.3	1.4	1.6	1.4	1.0
	Corner		1.3	1.5	1.5	1.1
No. of eggs per parasitized host	Equal	1.4	1.5	1.9	1.7	1.5
	Central	1.6	2.1	2.2	2.1	1.6
	Corner		2.0	2.0	2.0	1.8
Difference: observed—random parasitism of hosts exposed	Equal	0.0	.3	−2.4	−1.9**	− .6
	Central	.4	−1.0**	−2.4**	−3.3**	−1.2
	Corner		− .8	− .7	−2.9**	−3.6

*Different from equal distribution at five per cent level of significance.
**Difference between number of hosts parasitized and number that would be parasitized if parasite eggs had been distributed randomly among hosts exposed is significant at five per cent level.

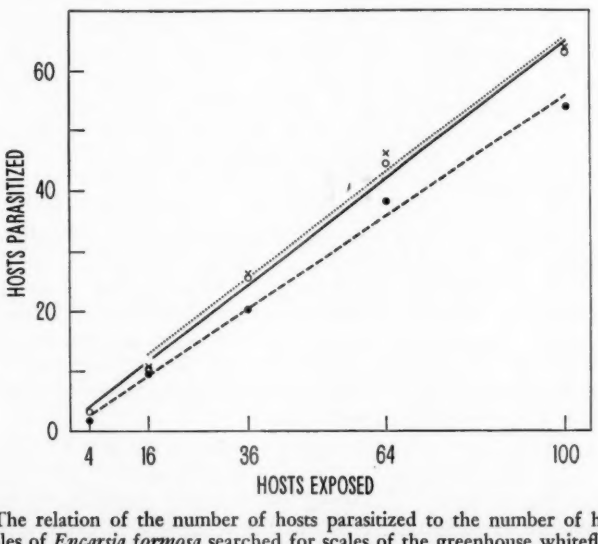

Fig. 2. The relation of the number of hosts parasitized to the number of hosts exposed when 20 females of *Encarsia formosa* searched for scales of the greenhouse whitefly distributed in three patterns on a 25-square-inch plane. Equal distribution: broken line. $y=24.92+0.55$ (x-44); centre distribution: solid line. $y=29.50+0.63$ (x-44); corner distribution: dotted line. $y=36.90+0.63$ (x-54).

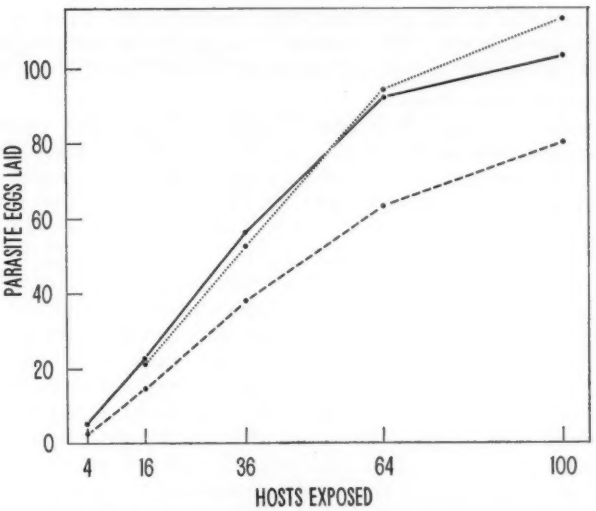

Fig. 3. The relation of the number of parasite eggs laid to the number of hosts exposed when 20 females of *Encarsia formosa* searched for scales of the greenhouse whitefly distributed in three patterns on a 25-square-inch plane. Equal distribution: broken line; centre distribution: solid line; corner distribution: dotted line.

I) were: number of hosts parasitized, 20.2; number of eggs deposited, 38.3; and percentage parasitism, 56.1. The comparable figures for the four-square-inch area were 33.5; 73.7; and 93.1. The large differences between the two sets of values indicate that the level of parasitism that occurred in the 25-square-inch area did not result solely from the suitability of the host scales to the parasite females.

Parasite Oviposition

The total numbers of eggs deposited by the 20 parasites at the three distributions and five host densities are recorded in Table I. As with the number of hosts parasitized, there was an increase in parasite oviposition with increase in host density. Although more eggs were laid, at all densities, with colonial distributions of host scales significant differences between the equal and colonial distributions occurred only at densities of 64 and 100. With up to 64 hosts the increase in the number of eggs laid by the parasites varied, approximately, as host density (Fig. 3). The increase in oviposition was less as host density changed from 64 to 100 and it seems likely that the potential reproductive power of the parasite was approached.

In Table I the influence of host density on the oviposition of *E. formosa* was determined by calculating the number of parasite eggs laid for each host exposed. As was to be expected, there were more eggs per host in the contagious than in the equal distribution. But in the experimental area and with 20 parasites searching there was an optimum range of host density for parasite oviposition. At the lower host densities, oviposition increased more rapidly than host density and at the higher densities it increased more slowly than host density. This trend probably resulted from the increasing contacts between host and parasite with increase in host density and from the failure of the supply of parasite eggs to keep up with the greater number of contacts at the higher densities. The average

number of eggs laid in the parasitized hosts followed the trend of the number of eggs per host exposed. The number of eggs per parasitized host gives an indication of the level of superparasitism at the various densities and distributions.

Distribution of Parasite Progeny

The manner in which the parasite distributed its progeny among the hosts it found indicates some of the factors involved in the process of searching the environment. If the parasite deposited its eggs entirely by chance, the number of hosts that would be attacked could be calculated from Thompson's (1939) formula,

$$Y = N\,(1-e^{-X/N}),$$

where Y=number of hosts parasitized, N=number of hosts exposed, e=base of natural logarithms, and X=number of eggs deposited among N hosts. The difference between the observed average and the calculated average for each set of the 10 replicates is given in Table I. In most cases there were fewer hosts attacked than would result from a random distribution of parasite progeny. For the equal distribution, the greatest difference occurred at the median density and the parasite tended to approach a random distribution as host density increased above this point. The differences for the colonial distributions were generally greater than those at comparable densities of the equal distribution, and usually increased with increase in host density. These differences in the number of hosts parasitized are relatively small, amounting to 10 per cent or less of the observed numbers, but it is clear that some hosts were more susceptible than others to attack by the parasites.

The distribution of the parasite progeny was examined in more detail, in Table II, by listing the number of hosts receiving 0, 1, 2, 3, . . . eggs and comparing the observed distribution with that of a random distribution calculated by means of Stoy's (1932) formula,

$$N \times {}_{X-P}C_P \left(\frac{1}{N}\right)^P \left(\frac{N-1}{N}\right)^{X-P},$$

where N=number of hosts exposed, X=number of parasite eggs, P=number of parasite eggs received by a host, and ${}_{X-P}C_P$ =number of ways in which a group of P eggs can be chosen from the total number of eggs deposited. The total of the calculated values differed slightly in some cases from that of the observed numbers because only five-place logarithms were used in the computations. Also, the differences between the number of hosts parasitized in the observed and calculated distributions listed in Table I and in Table II are not the same because averages were used in the former table and totals in the latter.

The general trend of progeny distribution which was postulated from Table I is confirmed by Table II. The latter table indicates that the parasite distributed its eggs in a random manner at the two lower host densities. With further increase in host density, the number of unparasitized hosts was greater, the number of hosts receiving a single egg was less, and the number of hosts receiving a relatively large number of eggs was greater in the observed than in the calculated series. However, as host density increased from the median to the upper limit, the parasite tended to distribute its progeny in a random manner. Although the parasite aggregated its eggs, the scales receiving one egg formed the largest group of parasitized hosts at all five densities.

Effects of Host Distribution and Parasite Density

The modification of the relation of parasite reproduction to parasite density by variation in host distribution was examined when various numbers of the

TABLE II

Comparison of observed and random frequency distributions of progeny by 20 females of *Encarsia formosa* among various numbers of hosts distributed in equal pattern

Eggs per host	Number of hosts exposed									
	4		16		36		64		100	
	Obs.	Cal.	Obs.	Cal.	Obs.	Cal.	Obs.	Cal.	Obs.	Cal.
0	19	18.7	63	63.3	158	123.8	258	237.2	454	448.3
1	14	14.4	59	58.9	97	132.1	208	235.7	347	359.5
2	5	5.4	27	27.3	60	70.3	114	116.9	147	143.9
3	2	1.2	9	8.3	29	24.9	46	38.6	48	38.3
4		.2	2	1.9	7	6.6	7	9.5	4	7.7
5					6	1.4	3	1.9		1.2
6					1	.2	3	.3		.4
7					1					
8					1					

parasite, i.e., 2, 4, 8, 16, 32, and 64, were introduced into equal, central, and corner distributions of 36 host scales.

Level of Parasitism

The number of hosts parasitized by the various numbers of parasites searching for whitefly larvae distributed in three patterns are recorded in Table III and shown in Fig. 4. There was a rapid increase in parasitism with initial increase in parasite density, but the increase in hosts parasitized declined rapidly with further increase in parasite density. An indication of the increases in parasitism is given by the percentages of hosts exposed that were parasitized. Significantly more hosts were found in the colonial distributions than in the equal distribution only at a parasite density of two. When the parasite density was transformed to natural logarithms the relation of the number of hosts parasitized to the number of parasites searching was approximately linear. For the central and corner distributions the relationship was significantly curvilinear but the sum of squares for linear regression accounted for at least 97 per cent of that of the density means. In this case, a linear regression gives a sufficiently accurate description of the relation of parasitism to parasite density. The regression coefficients and means of the equal and colonial distributions are not significantly different.

Parasite Oviposition

The numbers of eggs laid by the parasites searching for hosts distributed in the three patterns are recorded in Table III and shown in Fig. 5. As parasite density increased there was an increase in the number of eggs deposited. Although the hosts that were distributed in the colonial patterns usually received more eggs than those in the equal distribution, the differences were significant only for the central distribution at parasite densities of 2, 8, and 16. For all three distributions, as the number of female parasites increased from 8 to 64 the

TABLE III

Reproduction of *Encarsia formosa* when various numbers of female parasites searched for 36 hosts distributed in three patterns on a 25-square-inch plane (means of ten replicates)

	Distribution	Number of parasites searching					
		2	4	8	16	32	64
No. of hosts parasitized	Equal	8	14	18	25	30	32
	Central	10**	16	19	29**	30	34**
	Corner	10**	14	19	26	30	32
No. of parasite eggs laid	Equal	9	17	24	52	77	102
	Central	11**	18	30**	61**	86	112
	Corner	11	16	28	60	79	107
Percentage of hosts parasitized	Equal	22	40	51	68	84	90
	Central	28	44	54	79	84	94
	Corner	27	40	51	73	84	89
No. of hosts parasitized per female	Equal	4.0	3.6	2.3	1.5	.9	.5
	Central	5.0	4.0	2.4	1.8	1.0	.5
	Corner	4.8	3.6	2.3	1.6	.9	.5
No. of eggs per parasitized host	Equal	.9	1.2	1.3	2.1	2.5	3.2
	Central	1.1	1.2	1.6	2.2	2.8	3.3
	Corner	1.1	1.1	1.5	2.3	2.6	3.3
No. of eggs per parasite	Equal	4.4	4.2	3.0	3.2	2.4	1.6
	Central	5.7	4.6	3.8	3.8	2.7	1.8
	Corner	5.3	4.1	3.4	3.7	2.5	1.7
Difference: Observed—random parasitism of hosts exposed	Equal	.3	1.0	1.1*	−2.8*	−1.1	−1.4*
	Central	.4	1.4*	−1.1*	− .9	−2.2*	− .6
	Corner	.4	1.2	− .7	−3.0*	−1.8*	−2.0*

*Differences between number of hosts parasitized and the number that would be parasitized if parasite eggs had been distributed randomly among hosts exposed is significant at five per cent level.
**Different from equal distribution ar five per cent level of significance.

number of parasite eggs deposited tended to vary as the common logarithm of parasite density. A measure of the relative rates of increase in hosts attacked and in parasite eggs deposited can be obtained in Table III from the number of eggs laid per parasitized host. Superparasitism increased about threefold in the range of parasite density tested and in general was slightly higher when the hosts were in colonies.

Table III indicates that the efficiency of the individual female parasite dropped markedly as the number of parasites searching for 36 hosts was increased from two to 64. As the parasite density increased 32-fold the average number of hosts parasitized per female parasite dropped from four or five to 0.5. At the lower densities the parasite was slightly more efficient in the contagious distributions but all three distributions gave similar results at the higher parasite densities. The number of eggs per parasite also decreased with increase in parasite numbers and, as was to be expected, the grouping of hosts resulted in slightly higher rates of oviposition. An unusual feature of all three distributions is the fact that whereas, in general, there was a decline in oviposition with increase in parasite numbers, the number of eggs per female parasite increased when parasite density was increased from eight to 16 individuals. This results, in all probability, from a marked increase in the number of contacts between hosts and parasites in this particular range of host and parasite density.

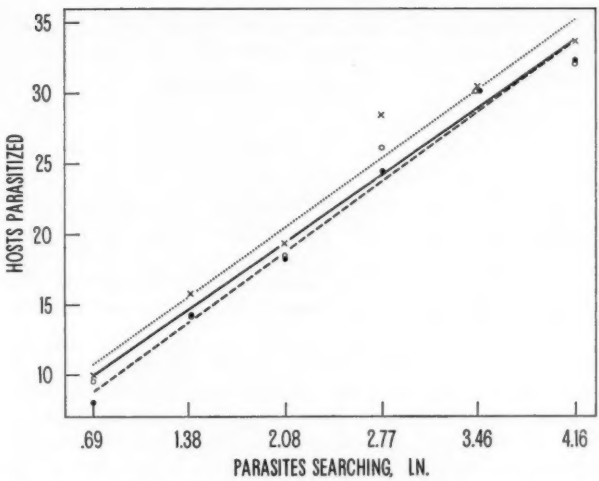

Fig. 4. The relation of the number of hosts parasitized to the number of parasites that searched for 36 scales of the greenhouse whitefly distributed in three patterns on a 25-square-inch plane. Equal distribution: broken line. $y=21.30+7.24$ (ln $x-2.42$); centre distribution: dotted line. $y=22.97+7.08$ (ln $x-2.42$); corner distribution: solid line. $y=21.78+6.92$ (ln $x-2.42$).

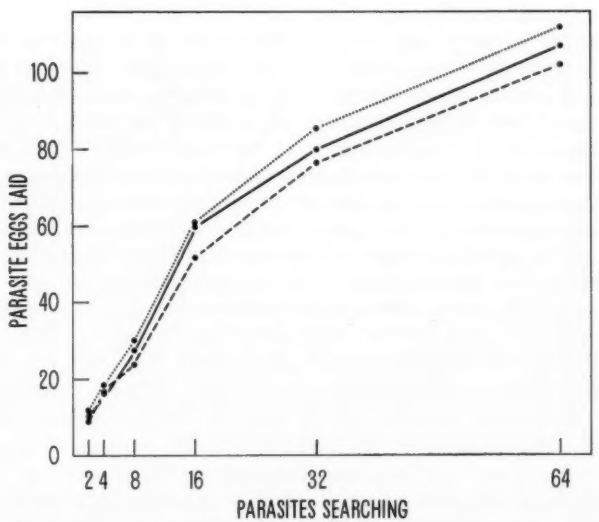

Fig. 5. The relation of the number of parasite eggs laid to the number of parasites that searched for 36 scales of the greenhouse whitefly distributed in three patterns on a 25-square-inch plane. Equal distribution: broken line; centre distribution: dotted line; corner distribution: solid line.

TABLE IV

Comparison of observed and random frequency distributions of progeny by various numbers of *Encarsia formosa* among 36 hosts distributed in equal pattern

Eggs per host	Number of female parasites											
	2		4		8		16		32		64	
	Obs.	Cal.	Obs.	Cal.	Obs.	Cal.	Obs.	Cal.	Obs.	Cal.	Obs.	Cal.
0	280	279.4	217	225.4	176	185.5	115	84.8	58	42.7	36	27.1
1	73	71.8	119	105.5	137	122.9	76	122.6	75	91.0	63	59.7
2	7	8.2	23	24.5	41	40.6	92	88.4	92	96.9	76	84.7
3			1	3.8	5	9.8	53	42.4	68	68.5	64	80.0
4					1	1.5	21	15.3	47	36.4	52	56.7
5							2	4.4	12	15.4	36	32.1
6							1	1.1	4	5.5	20	15.1
7									2	1.7	4	6.1
8									2	.4	7	2.2
9												.7
10											1	
11											1	

Distribution of Parasite Progeny

The manner in which the parasite distributed its progeny is indicated in Table III, in which the average differences for 10 replicates between the number of hosts parasitized and the number that would have been parasitized if the females deposited their eggs among the 36 hosts by chance are given for the parasite densities and host distributions. At the lower densities the parasite found more hosts than it would have for a random distribution of its progeny, but with increasing density there were fewer hosts parasitized than expected. The differences between the equal and contagious distributions were not consistent. The distribution of the parasite progeny was analysed in more detail in Table IV for the equal distribution, the calculated totals being determined by the formula of Stoy (1932). At the lower densities the parasites deposited single eggs in more scales than expected and avoided superparasitism to some extent. But with increase in density the number of hosts receiving a few eggs was less and the number receiving many eggs greater in the observed than in the calculated series. From Tables III and IV it is clear that the parasite concentrated its eggs in some hosts, to a limited extent, at the higher host densities.

Discussion

When hosts of *Encarsia formosa* were in colonies, more were parasitized than when they were uniformly distributed over the area of search. When 20 female parasites searched for various numbers of hosts the effect of host distribution on parasitism was evident, but when two to 64 parasites searched for 36 hosts the effect was greatly reduced. The increasing number of parasites nullified

the effect of host distribution because the larger numbers of *E. formosa* saturated the environment. The modification of the influence of parasite density on parasitism doubtless would have been more marked if the same numbers of hosts and parasites had interacted over a larger area. The influence of the colonial distributions resulted from the fact that the groups of hosts were more easily found by individual parasite females than were isolated hosts. This situation corresponds to that found by Parsons and Ullyett (1936). An individual parasite often examines several hosts thoroughly before ovipositing in one of them and, when it has found a group of hosts, it is able to contact several individual hosts much more easily than if the same number of hosts were isolated from one another. This situation is related to that postulated by Smith (1939). The colonial distribution of hosts resulted in a higher parasitism than an equal distribution because colonies, and therefore suitable individuals, are more easily found under these circumstances.

Whereas the distribution of the hosts modified the level of parasitism, the number of hosts parasitized was closely related to the number of hosts exposed and to the number of parasites present on the experimental area. A constant number of parasites found hosts in approximate proportion to the number of hosts exposed to attack. It seems that a given number of parasites covered a given percentage of the experimental area in their movements and therefore that a given percentage of hosts present was parasitized. With increasing numbers of *E. formosa* and a constant supply of hosts the rate at which hosts were discovered declined and the number of parasitized hosts varied as the natural logarithm of parasite density. In this case the greater the number of parasites present the greater was the overlap in movement of individuals over the experimental area, so that the increase in parasitism failed to keep up with the increase in numbers of parasite females.

Because of the varying levels of superparasitism that occurred at the various combinations of host distribution, host density, and parasite density, the relation of parasite oviposition to density was somewhat different from that of the number of hosts parasitized. However, only one parasite develops in a host scale and therefore the growth of host and parasite populations is related to the numbers of unparasitized and parasitized hosts that result from attack by the female parasites in any generation.

An unusual feature of the present experiments was the manner in which the parasites distributed their progeny. Although the differences between the observed distributions and those resulting from a random distribution of parasite eggs were not usually statistically significant, the trend of these differences was consistent. At both the higher host and parasite densities the parasite tended to concentrate its eggs in some hosts whereas, at the lower host and parasite densities, it overdispersed, to some extent, its progeny. This trend cannot be explained by the ratio of hosts to parasites for the results of the host density and parasite density series of experiments gave contradictory results. For example, when the number of hosts per parasite was high the parasite concentrated its progeny in the host-density series and avoided parasitized hosts in the parasite-density series. The important factor in this connection, however, was the number of contacts between parasites and hosts and this was determined by the densities of the two species rather than the ratio of numbers. This effect of density on distribution of parasite progeny was greatly modified by the general restraint in oviposition. As the oviposition of *Encarsia* was greatly reduced (see below) it is likely that many hosts were not fully acceptable to the parasite females. This is further

supported by the fact that the greatest concentration of parasite eggs occurred when the hosts were aggregated and the acceptable ones more easily contacted.

The concentration of parasite progeny in comparison to a random distribution is not peculiar to *Encarsia formosa*. For example, the frequency distribution of parasite progeny was investigated by Ullyett and the empirical distribution of parasite eggs may be compared with that obtained from the formula of Stoy (1932). When the distribution of the number of eggs per host laid by *Bracon* (=*Microbracon*) *hebetor* Say among increasing numbers of paralysed hosts (Ullyett, 1945, Tables I, III) is compared with a random frequency it is seen that fewer hosts received one egg and more hosts many eggs than expected. The same relationship existed when increasing numbers of females of *Chelonus texanus* Cress. oviposited in a constant number of its hosts, the eggs of *Anagasta kühniella* (Ullyett, 1949a, Table II). *Cryptus inornatus* Pratt (Ullyett, 1949b) deposited its progeny at random as the density of paralysed hosts increased but increasing numbers of parasites avoided the middle frequencies while the lower and upper frequencies were greater than expected.

In both the host-density and the parasite-density series of experiments the reproduction of *Encarsia* appeared to be considerably below its potential oviposition. The sharp change in the trend of oviposition with increase in host density (Fig. 3) as the number of hosts exposed was increased from 64 to 100 individuals indicates that the maximum fecundity was approached. At the maximum number of hosts per parasite (five hosts: one parasite) in the host-density series the number of eggs per female was 4.05, whereas in the parasite-density series (18 hosts: one parasite) it was 4.35 eggs per female. The oviposition by female parasites of the same age is about double these values in the absence of a density effect. As the parasites concentrated their eggs in some hosts it is possible that all scales were not equally acceptable to all females. The general level of parasitism, i.e., the means and coefficients of the regression lines in Figs. 2 and 4, probably resulted from the seasonal influence of environmental conditions, that occurred during the rearing of the experimental animals in the greenhouse, on the egg supply of the female parasites and on the many characteristics of the host larva that make it acceptable to the parasite for oviposition. The effects of these environmental factors are so subtle and the oviposition of the parasite so sensitive to them that it would be very difficult to analyse their interaction in a quantitative manner. In view of this, the first replicate of all host distributions and host densities was completed before a second was started, and so on until the tenth was finished. The host distribution and parasite density series was treated in a similar manner.

Acknowledgment

The technical assistance of Mr. G. D. Williamson is gratefully acknowledged.

Summary

When *Encarsia formosa* searched for increasing numbers of fourth-instar larvae of *Trialeusodes vaporariorum* distributed over a 25-square-inch area, the efficiency of the parasite was increased by a colonial distribution of the host, the parasite found hosts in approximate proportion to the number of hosts exposed, and the parasite females tended to under-disperse their eggs at the higher host densities. When various numbers of parasites searched for a constant number of hosts a colonial distribution of the host did not significantly increase the efficiency of the *Encarsia* female, the parasites tended to find hosts in proportion to the natural logarithm of parasite density, and the parasite concentrated its progeny in some hosts except at the lower parasite densities.

References

Parsons, F. S. and G. C. Ullyett. 1936. Investigations on *Trichogramma lutea*, Gir., as a parasite of the cotton bollworm, *Heliothis obsoleta*, Fabr. *Bull. Ent. Res.* 27: 219-235.

Smith, H. S. 1939. Insect populations in relation to biological control. *Ecol. Monogr.* 9: 311-320.

Stoy, R. H. 1932. Appendix: Superparasitism by *Collyria calcitrator*, Grav. *Bull. Ent. Res.* 23: 215-216.

Thompson, W. R. 1939. Biological control and the theories of the interactions of populations. *Parasitology* 31: 299-388.

Ullyett, G. C. 1945. Distribution of progeny by *Microbracon hebetor* Say. *J. Ent. Soc. S. Africa* 8: 123-131.

Ullyett, G. C. 1949a. Distribution of progeny by *Chelonus texanus* Cress. (Hymenoptera: Braconidae). *Canadian Ent.* 81: 25-44.

Ullyett, G. C. 1949b. Distribution of progeny by *Cryptus inornatus* Pratt (Hymenoptera: Ichneumonidae). *Canadian Ent.* 81: 285-299.

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A New Species of *Triaspis* Haliday (Hymenoptera: Braconidae) from Ontario[1]

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***Triaspis* (*T.*) *xanthochila* sp.n.[3]**

This species is closely related to *Triaspis* (*T.*) *halidayi* Martin, from South Dakota, and *Triaspis* (*T.*) *kurtogaster* Martin, from eastern North America. In all three species the abdominal carapace is relatively strongly longitudinally rugoso-punctate and apically emarginate, and the clypeus is transverse. The new species may be readily distinguished from *kurtogaster* by its non-reflexed margin of the clypeus and by its less strongly developed marginal lamella of the third abdominal tergite, and may be separated from *halidayi* by its stronger, coarser, general rugoseness and darker colour.

Holotype, ♀.—Length 4 mm. Black except for the following: labrum testaceous; mandible dark testaceous with darker brown at base and apex; palpi yellowish; antennal scape, pedicel, and the two basal flagellar segments with brownish infusions; legs rufotestaceous except for the darker brown base of the hind coxa. Wings hyaline with the costa and stigma dark brown, the remaining veins paler, particularly towards the bases of the wings.

Head quadrate in general outline, nitidous, and more or less punctate; vertex, temple, and genal region smooth and shiny; frons densely but evenly punctured; fronto-clypeal groove well impressed, with a large, deep, elongate, anterior tentorial pit at each end. Clypeus transverse, the dorsal part irregularly but evenly punctate, the very narrow anterior margin impunctate and nitidous and having rather fine transverse striations; central part of margin straight in outline, not reflexed, and with a rather definite angulation in the margin near the base of each mandible. Labrum transverse; margin slightly rounded and evenly covered with setigerous punctures. Palpi elongate. Antennal scapes very well separated, with a rather low smooth ridge between them and with a few dorsolateral rugae in the depression behind each. Ocelli large, circular,

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[3]From, ξαμθοσ, yellow, and χειλοσ, lip; in allusion to the yellowish labrum.

each with a more or less definite bordering groove; interocellar triangle smooth and slightly depressed. Antennae broken, at least 21-segmented, all segments very closely and evenly punctate, and with a dense, very short pile; scape short and stout, with the inner margin rather distinctly rounded; pedicel of moderate length; first flagellar segment wider than the second, which is the longest, the remaining segments being progressively shorter. Occipital carina complete and well developed, especially towards the base of the mandible.

Thorax short and stout; mesonotum nitidous, the general surface being evenly covered with fine setigerous punctures; notauli very strongly impressed, foveolate with fairly deep punctures, proceeding caudally towards the scutellar groove; area of convergence broadly depressed and irregularly punctate; median lobe finely punctate, the anterolateral corners being finely irregularly punctate; lateral lobes roundish and sparsely, but finely, punctured, the lateral ridge being narrow. The posterior-lateral carina narrow but flangelike and fairly well developed. Scutellar groove rather broad, deep, with one strong central carina, and with the lateral areas irregularly rugose. Scutellum trigonal in outline, rather flat, with a few scattered setigerous punctures, and without any strong bordering carinae; side of scutellum with a triangular rugose area. Metanotum transverse, slightly narrower centrally, and with relatively strong rugae in the rectangular lateral areas. Propodeum irregularly rugose, with a rather narrow dorsal area and with the posterior surface dropping obliquely to the point of abdominal articulation; central dorsal carina rather short but strongly developed, joining the strong transverse carina which extends posterolaterally towards the strongly developed lateral protruberance, and delimiting rectangular, relatively smooth, nitidous areas on the dorsal surface; posterior surface of propodeum nitidous but coarsely rugoso-punctate; lateral area very strongly irregularly rugoso-punctate, the propodeal spiracle circular and very small. Mesopleuron nitidous; upper anterior corner with a protruding area that is rugoso-punctate at its base; upper posterior corner and central region impunctate; lower-central area depressed into a sinuate punctate mesopleural groove. Lateral area of pronotum nitidous, and for the most part evenly punctured except for the upper area, which is impunctate; upper posterior corner rather rugose. Tegula shiny, with fine setigerous punctures. Wings hyaline, stigma a little longer than twice its greatest width, second discoidal cell shorter than the first. Legs relatively long and covered with a whitish pile, hind femora relatively stout; all tarsal segments progressively shorter except for the fifth. Each tarsal claw with a basal tooth.

Abdomen elongate and not very strongly rounded, the general surface longitudinally rugoso-punctate; basal part of first tergite relatively smoother and leaving a slight dorsal depression; both transverse grooves evident, each composed of a row of deep punctures between the longitudinal rugae; the three tergites each with a reflexed lateral ridge, that of the third being thinnest and bordering the apical emargination of the carapace. Ovipositor relatively short, almost two-thirds as long as the carapace; sheath slender and relatively densely clothed with long, fine hairs.

Holotype, ♀.–Belleville, Ontario; 4-VI-56 (H.C. Coppel) [C.N.C. No. 6494].

Paratype.–Ontario; 1 ♀, topotypical; 4-VI-56 (G.W. Thompson) (head on point) [C.N.C.].

Specimens Examined.–Only the two type specimens were examined. They are practically identical in structure and colour.

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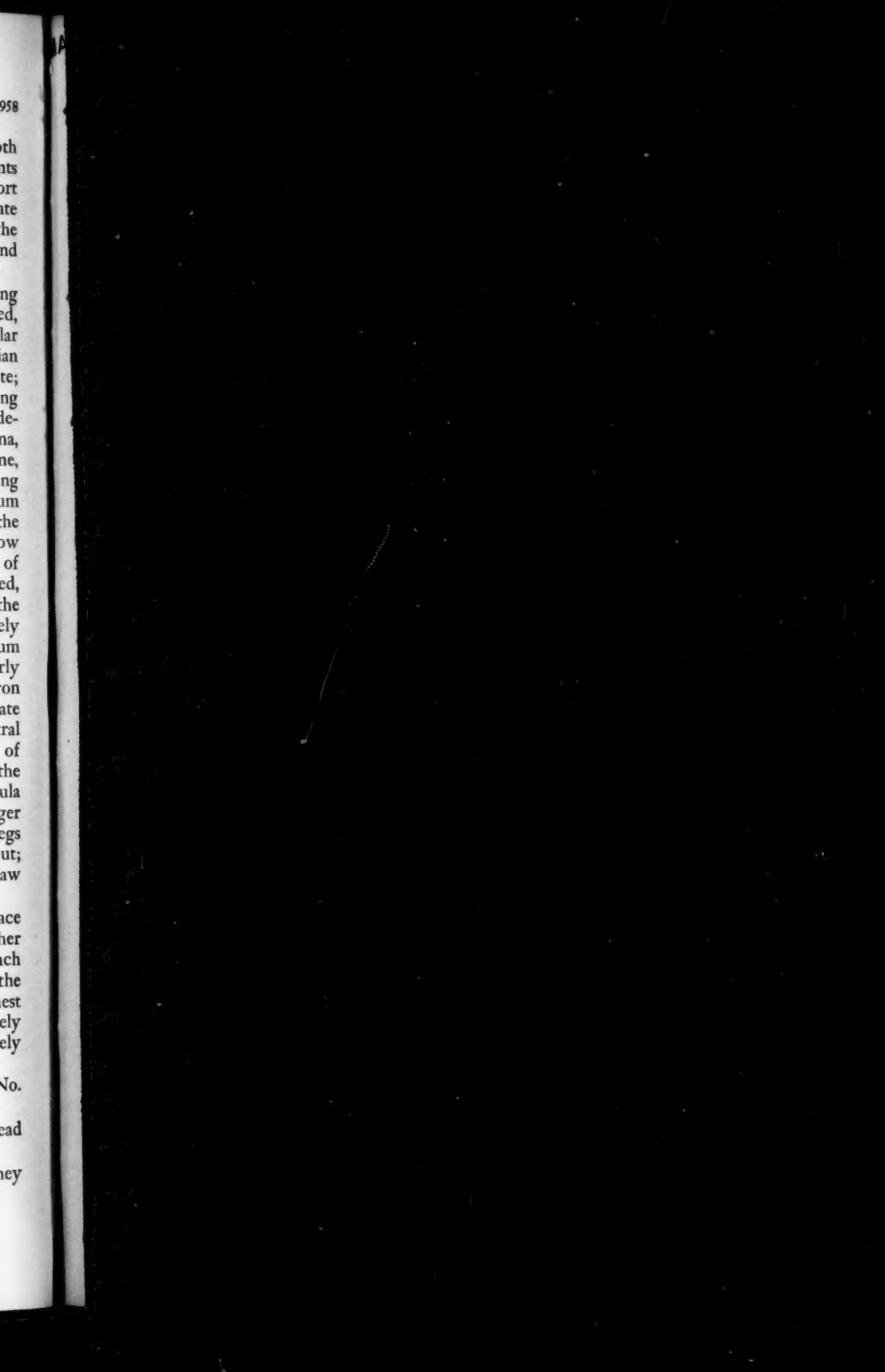
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